NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-353

Semiannual Review of

Research and Advanced Development

January 1, 1967 to June 30, 1967

Volume I. Supporting Research and Technology for the Office of Space Sciences and Applications, National Aeronautics and Space Administration

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

July 31, 1967

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Approved by:

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Technical Memorandum 33-353, Vol. I

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PREFACE

This document has been prepared under the direction of the Office of Research and Advanced Development of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

The Semiannual Review of Research and Advanced Development is published in three volumes directed to the appropriate NASA funding offices:

Volume I	Supporting Research and Technology for the Office of Space Sciences and Applications
Volume II	Supporting Research and Technology for the Office of Advanced Research and Technology
Volume III	Supporting Research and Technology for the Office of Tracking and Data Acquisition (New Systems and Spacecraft Subsystems)

This issue reports progress for the period of January 1 to July 31, 1967, Fiscal Year 1967. Preceding issues were published as follows:

Fiscal Year	Calendar Period Covered	JPL Technical Memorandum No.	Publication Date
1965	January 1 to June 30, 1965	33-243	August 15, 1965
1966	July 1 to December 31, 1965	33-272	January 31, 1966
1966	January 1 to June 30, 1966	33-296	July 31, 1966
1967	July 1 to December 31, 1966	33-322	January 31, 1967

PART A. LUNAR AND PLANETARY EXPLORATION

SCIENCE (185)

Space Chemistry (185-37)

Astronomy (185-41)

PART A. (contd)

PART A. (contd)

PART A. (contd)

Spacecraft and Capsule Equipment Development (186-68) (contd)

PART A. (contd)

Spacecraft and Capsule Equipment Development (186-68) (contd)

PART A (contd)

PART B. PHYSICS AND ASTRONOMY

PART C. BIOSCIENCE

PART C. (contd)

INTRODUCTION

This volume contains a review of all supporting research and technology in progress at the Jet Propulsion Laboratory during the period January 1 to June 30, 1967, under direction of the JPL Office of Research and Advanced Development, for the NASA Office of Space Sciences and Applications.

The work units are arranged in numerical sequence by NASA code in each subject section. To locate a desired unit, refer to the Table of Contents under the appropriate subject heading.

JPL research and advanced development results published during this report period as JPL documents and in the open literature are listed under each work unit.

Part A

Lunar and Planetary Exploration

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SCIENCE (185)

SPACE CHEMISTRY (185-37)

LUNAR AND PLANETARY X-RAY DIFFRACTION
NASA Work Unit 185-37-20-02-55
JPL 383-30201-2-3250

J. A. Dunne

OBJECTIVE

The principal objective of the Lunar and Planetary X-Ray Diffraction Program is the development of instrumentation and instrumental concepts capable of conducting mineral phase analysis on the surfaces of the moon and Mars. X-ray diffraction and supporting fluorescence techniques form the overall experimental framework of the effort. The project will be complete at the end of FY 1967. Instrument development has reached a level such that flight instrumentation can be derived from existing breadboards.

PROGRESS

Instrumentation Research

The major effort during FY 1967 has involved the design, fabrication, and experimental evaluation of auxiliary X-ray fluorescence analysis instrumentation intended to provide crude information on sample composition with respect to the elements Al, Si, K, Ca, Fe, and Ni. Balanced filters (Ref. 1) are used as dispersive elements in order to judge the merits of this technique relative to electronic dispersion (pulse height analysis). Table 1 gives the performance data collected using standard samples consisting of mixtures of the element oxides with Si and a methyl cellulose binder, the latter approximately 50% by weight. Also listed are the pass and absorption filters used for the analyses, and the compounds from which they were made. Figures in parentheses give the element-equivalent filter area densities in mg cm^{-2}, measured at the balancing wavelength. With the exception of the metal foils (asterisks), all of the filters consist of the powdered compounds in a polystyrene matrix. The breadboard analyzer layout is sketched in Fig. 1. Data obtained using analyzed rock specimens provided by A. A. Loomis are summarized in Fig. 2. The rocks are metavolcanics from the California Sierra with a SiO_2 range between 52 and 68% by weight (Ref. 2). It has been concluded from this work that the balanced filter technique offers a satisfactory method of dispersion in the Z region studied. The primary X-ray flux available at the sample surface in the Lunar X-ray diffractometer is more than adequate to allow X-ray fluorescence analysis of the elements Al, Si, K, Ca, Fe, and Ni when they exist in the sample in amount greater than 1% by weight. The Cu target X-ray tube is, however, far from optimum for the analysis of Al and Si. The relatively poor performance on Si and Al, combined with escape peak interference with Ca and K analyses, suggests the use of Ne rather than Ar counting gas in this particular application.

Research and Instrument Development Summary Report

The primary task which is being accomplished during the remaining weeks of FY 1967 is the collection, critical review, and assembly into a summary report of all the research and instrument development work that has been done in the course of the Lunar and Planetary X-Ray Diffraction Program at JPL. Other tasks being

completed for the summary report are: radioisotope source feasibility review, minimum-performance margin analysis, and data reduction studies.

REFERENCES

1. Dunne, J. A., "The Application of Ross Filters to the Non-Dispersive Analysis of Aluminum and Silicon," Norelco Reporter Vol. XIII, No. 1, pp. 21-24, January-March 1966.

2. Loomis, A. A., "Contact Metamorphic Reactions and Processes in the Mt. Tullac Roof Remnant, Sierra Nevada, California," Journal of Petrology, Vol. 7, No. 2, pp. 221-245, June 1966.

PUBLICATIONS DURING REPORT PERIOD

Meetings and Symposia Papers

1. Dunne, J. A., and Nickle, N. L., "Balance Filters for the Analysis of Al, Si, K, Ca, Fe and Ni," presented at the 2nd Symposium on Low Energy X- and Gamma-Ray Sources and Applications, held at the University of Texas in Austin, March 1967 (to be published in a Proceedings Volume and as JPL TR 32-1134).

ANTICIPATED PUBLICATIONS

JPL Technical Memorandum

1. Dunne, J. A., and Nickle, N. L., The Lunar and Planetary X-Ray Diffraction Program Summary Report.

Table 1. Performance data

Element	Wavelength, Å	Pass filter	Absorbing filter	Channels	Rate, counts/min channel/wt %
Al	8.34	$Al^{\bullet}$ (4.53)	$Mg^{\bullet}$ (6.36)	35	30
Si	7.13	Si (5.45)	$Al^{\bullet}$ (8.15)	44	16
K	3.74	$KHCO_3$ (11.4)	S (19.8)	33	1800
Ca	3.36	$CaCO_3$ (14.4)	$KHCO_3$ (16.4)	41	540
Fe	1.94	MnO_2 (26.2)	Cr_2O_3 (29.6)	43	2100
Ni	1.66	Co (32.5)	Fe (36)	43	600

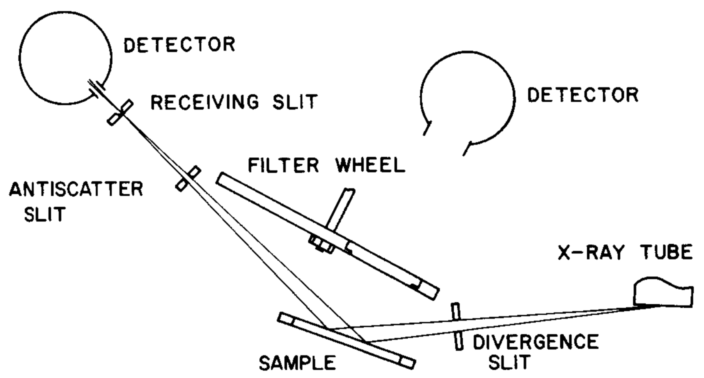

Fig. 1. Layout of breadboard analyzer

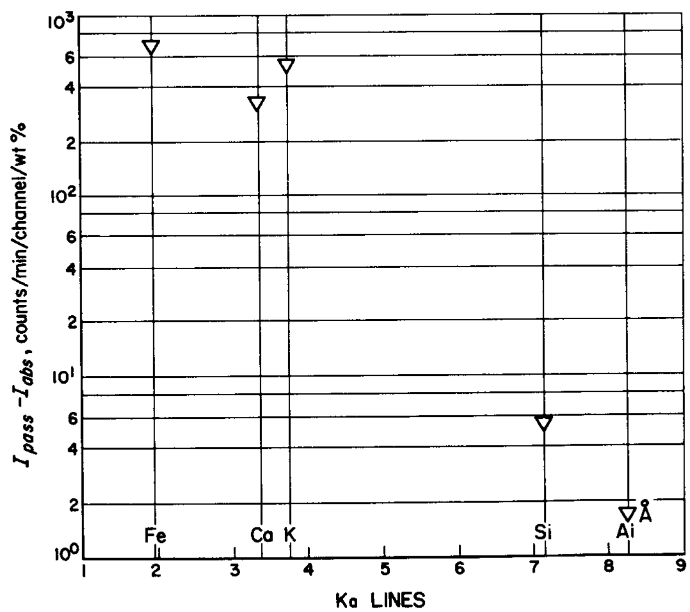

Fig. 2. Metavolcanic rock data

FLIGHT MODEL INTERFEROMETER

NASA Work Unit 185-37-20-10-55
JPL 383-32101-2-3250
383-32102-2-3230
R. Beer
R. A. Schindler

OBJECTIVE

The objective of this task is to develop a flightworthy, high-resolution (0.5 cm^{-1}) infrared (1.2 to 5 μ) Fourier-Michelson interference spectrometer for atmospheric analysis on advanced planetary missions (flyby or orbiter).

During FY 1968, the optical and electronic development of this system will continue to the point that a balloon flight test to observe the reradiation of the earth's atmosphere can take place early in FY 1969. This scheduling must be kept so that a proposal for Voyager 1975 can be properly prepared in early 1969.

This program is responsive to recommendations A2, A4, A5, and D3 of the Space Science Board Conference on the Martian Atmosphere (letter of December 9, 1966 from Dr. H. E. Newell). The ability to produce instrumentation of such high resolution is, to our knowledge, unique to JPL since no similar development is taking place elsewhere.

PROGRESS

Servo Drive System

On the basis of a specification prepared during the previous report period, five proposals were received for the construction of the servo-controlled drive system. The funds for this contract are FY 1966 funds from "Flight Model Interferometer," NASA Work Unit 818-01-06-70. The proposals were evaluated and Aeroflex Laboratories in Long Island was selected after inspection of their facilities. The contract has now been awarded and the work, which commenced at the end of February 1967, is progressing favorably.

An extensive analysis and design effort has been done on the servo-drive portion of the interferometer by R. Schindler as an aid for preparing the specifications for the servo-drive RFP and in evaluating the received proposals. This effort pointed out some very critical problems; namely, cat's-eye retro reflector structure resonances and reference-fringe detector drift. The structural resonance problem was overcome by using the cat's-eye secondary mirror for the higher frequency servo-loop corrections, thus reducing the mass to be driven by a factor of 10^4. The detection problem was overcome by varying the path-length at a high frequency and phase demodulating the detector output.

Optical System

The optical and mechanical systems for the interferometer are now largely designed and fabrication has commenced. A photoelectric autocollimation technique

has been devised for the alignment of the cat's-eyes. In view of the small focal ratio of these elements, such a technique is almost mandatory. The cat's-eyes are now in the process of assembly.

All components of the fore-optics, with the exception of the mirror housings, have been fabricated. The housings themselves are in process. The optical chopper has been specified and is now being manufactured by the Bulova Watch Company. Design of the main housing cannot be completed until the interface to the servodrive system is completely specified. This will occur within a few weeks.

Data Handling System

Design studies of the infrared detection system have been undertaken. As a consequence of the extremely short integration times available at each sample point (down to 2 ms/point), ambient temperature PbSe detectors have been chosen for the system. The spectrometer signal alternates between the target and a reference source while the total power is monitored by a second PbSe detector identical to the interferogram detector. Breadboard construction of the analog portion of the data system has commenced.

System Description

The entire system has been described by R. A. Schindler in JPL SPS 37-43, Vol. IV, pp. 253-257, Feb. 28, 1967.

PLANNED ACTIVITIES

During the second and third quarters of FY 1968, the servo-controlled drive system will be completed and integrated into the infrared optical system.

The data and optical systems will be designed and fabricated in-house by JPL personnel. These include the task leader, the cognizant engineer, a mechanical engineer, an electronics engineer, an electronics technician, and a mechanical technician, who will perform the following functions:

(1) Mechanical--design, fabrication, and assembly of:

- (a) Cat's-eye retro reflectors.
- (b) Input optics.
- (c) Optical chopper assembly.
- (d) Reference source system.
- (e) Collimating and condensing optics.
- (f) Drive-system interface.
- (g) Calibration facility.

(2) Electronics--design, test, and fabrication of:

   (a) Analog infrared detection system.

   (b) Signal integrators.

   (c) Digitizing system.

   (d) Power system.

   (e) Control system for thermoelectric IR detector cooling.

   (f) Optical chopper drive.

(3) Specify and procure both airborne and ground PCM telemetry equipment.

(4) Specify the digital data processing system and computer interfaces.

(5) Monitor the servo-drive contract: this implies the active participation of the cognizant engineer in the interfacing of the servo drive system.

(6) Generation of inputs for specification of functional requirements: this information provides the specifications to which the instrument is designed, and the standards for the evaluation of the completed instrument which employ both monochromatic and broadband laboratory IR sources, radiometric calibrations, and also astronomical tests at Table Mountain Observatory.

Late in FY 1968 procurement will be initiated for the balloon flight operations, including addition of a PCM telemetry system to our present capability as well as launch operations and support personnel. This effort will require FY 1969 funding.

Instrument testing will be both environmental and spectral. In particular, the system's capability of producing spectroradiometric data of high accuracy will be investigated.

PUBLICATIONS DURING REPORT PERIOD

Open Literature

1. Beer, R., "Fourier Spectroscopy From Balloons," Appl. Opt. 6, 209, 1967.

JPL SPS Contributions

1. Schindler, R. A., "Development Flight-Model Infrared Interferometer," SPS 37-43, Vol. IV., pp. 253-257, February 28, 1967.

ANTICIPATED PUBLICATIONS

None.

LUNAR AND PLANETARY GEOPHYSICAL MODELS

NASA Work Unit 185-37-20-12-55
JPL 383-32901-2-3250

Ray L. Newburn, Jr.

OBJECTIVE

Environmental models will be furnished for the bodies of the solar system as follows: the moon (to support Surveyor), Mars (to support Mariner and Voyager), and ultimately Venus, Jupiter, Mercury, comets, and other objects which may be the goals of advanced planetary missions. This work is partly supported by the Surveyor and Voyager Projects.

PROGRESS

Lunar Model and Studies

J. de Wys' suggested Surveyor experiment, the attachment of a small magnet and of a nonmagnetic control to a Surveyor footpad where they can be seen by the TV camera, has been accepted and will be included on Surveyors IV through VII.

Choate's work on contamination of the lunar atmosphere has been in abeyance because of his active participation in Surveyor flight operations and related SLUMP (Surveyor Lunar Mechanical Properties) working group activities. The report is virtually complete in first draft.

Mars Model

The Mars Scientific Model, Voyager PD-114, was released in preliminary form (about 70% complete) to selected Voyager users during April. Production of the "regular edition," a two volume loose leaf compilation, began June 19. It is scheduled to be available in the second quarter of FY 1968. The initial general release will be about 80% complete. Various studies in progress on atmospheric circulation and winds, cloud cover, and general atmospheric transparency, periodic and secular surface changes, etc., will be added to the document as they are completed during the coming fiscal year.

Advanced Missions

Two technical memoranda done in conjunction with the Advanced Technical Studies Office appeared during the reporting period (see publication list). One of these (JPL TM 33-332) was somewhat obsolete scientifically by the time of its appearance. It is anticipated that a completely new Venus study will be undertaken after the Mariner V flyby. A document on the "grand tour" of the major planets will also be undertaken with the ATS office during the coming fiscal year.

PUBLICATIONS DURING REPORT PERIOD

JPL Technical Memorandums

1. Brereton, R. G., Newburn, R. L., et al., Mission to a Comet: Preliminary Scientific Objectives and Experiments for Use in Advanced Missions Studies, TM 33-297, February 15, 1967.

2. Brereton, R. G., Newburn, R. L., et al., Venus/Mercury Swingby with Venus Capsule. Preliminary Science Objectives and Experiments for Use in Advanced Mission Studies, TM 33-332, May 1, 1967.

ANTICIPATED PUBLICATIONS

Open Literature

1. de Wys, J., "On the Geological Interpretation of Rayed Lunar Craters" (in preparation).

2. de Wys, J., "Interpretations of Patterning in Surveyor III Photographs" (in preparation).

3. de Wys, J., and Smith, H. T. U., "Linear Features on Mariner IV Photographs" (in preparation).

JPL Technical Report

1. Choate, R., Evaluation of Surveyor Exhaust Effects on the Moon (in preparation).

JPL SPS Contributions

1. de Wys, J., and Smith, H. T. U., "Linear Martian Features on Mariner IV Frames 3 and 11," SPS 33-45, Vol. IV (in press).

2. Brereton, R. G., and Newburn, R. L., "Mission to a Comet (Constraints and Background Information)," in press.

ANTICIPATED PUBLICATIONS

JPL Project Document

1. Mars Scientific Model, Voyager PD-114, in press.

GAMMA-RAY SPECTROSCOPY
NASA Work Unit 185-37-20-13-55
JPL 383-31301-2-3250
A. Metzger

OBJECTIVE

Gamma-ray and X-ray spectroscopy can be used to furnish data on the chemical composition of lunar and planetary surfaces by measuring the intensity and characteristic energy of radiation emitted between 1 keV and 10 MeV. The measurement and interpretation of this information will shed light on the evolution and origin of the body in question, by determining if it has undergone substantial differentiation during its development. The objective of this program is to develop the experimental techniques for such measurements to be made near or on those lunar and planetary surfaces where the environment permits. Very similar instrumentation can also be applied to celestial observations of X-ray and gamma-ray spectra from both diffuse and point sources.

PROGRESS

Accelerator Tests

A high-energy proton accelerator will induce the same radioactivities as a flux of primary cosmic rays or high-energy solar protons in space. Preparations for use of the Bevatron at Berkeley were completed late last year and a determination of beam characteristics at the access collimator begun. A major shutdown of the machine in January has interrupted this work. The target materials FE, SiO_2, Al, Al_2O_3, Mg, basalt, and dunite have all been received and prepared for use. The Bevatron is expected to be back in operation in July.

Lunar X-Ray Fluorescence

An experimental evaluation has been made of the effectiveness of the solar X-ray flux in inducing characteristic-line fluorescent emission from the lunar surface. The solar X-ray flux determined by satellite and rocket experiments has been duplicated in the laboratory between 1 and 14 keV by measuring a succession of bremsstrahlung spectra with five different X-ray targets at varying X-ray potentials. These bremsstrahlung spectra, about 50 in all, have been fed into a least-squares computer program to choose the components for approximating the solar spectrum. The results of measurements using both pure elements and rock samples have shown that, for the quiet solar X-ray flux at the maximum of the eleven year cycle, the lunar surface will generate about 100 characteristic photons/cm^2s sr in the silicon group (Si, Mg, Al) 1 photon/cm^2s sr in the calcium group and 0.5 photon/cm^2s sr in the iron group. Each gives enough line emission for detection at the surface or from a close lunar orbit.

The intensity of particle-induced fluorescence from the moon has been investigated theoretically, making use of the experimental data taken by Khan, Potter, and Wosley at Lawrence Radiation Laboratory. Large proton flares would produce

fluxes approximately 1/10th the X-ray flux caused by solar X-radiation from the quiet sun at solar maximum; the enhanced solar X-radiation from such a flare would allow us to neglect the proton-induced component of fluorescence. It has now been demonstrated that the moon intercepts the earth's magnetospheric tail. If the magnetosphere contains an electron flux on the order of $10^6/cm^2$ s or greater at this radius, induced lunar fluorescence should be measurable from lunar orbit at certain predictable times. Experiments are planned to confirm this estimate. On the other hand, our calculations indicate that small proton fluxes, the solar wind, and cosmic ray particles all produce negligible fluorescence from the lunar surface in comparison with that caused by the solar X-ray flux from the quiet sun at solar maximum.

X-Ray Detector System

The 20 cm^2, thin window (1/4 mil Mylar) X-ray proportional counter under development for a lunar fluorescence experiment (0.5 to 12 A range) was completed. Preliminary test results showed very satisfactory resolution (17 to 18% for $MnK_{(\alpha)}$, but a deterioration with time which may require use of a gas flow system instead of a sealed tube (Fig. 1).

The proportional counter was assembled into a system suitable for balloon flight. Included in the system was an anticoincidence shield of scintillating plastic, completely surrounding the detector, with an opening for the detector collimator (Fig. 2). A trolley arrangement on the gondola frame in which the detector is mounted provides for moving a calibration source or a blocking crystal in front of the collimator opening. Power supplies developed in the Ranger program were utilized to provide high voltage to the proportional counter and the two phototubes used in the gondola.

All electronics carrying high voltage were potted with Solithane, and vacuum and thermal tests successfully carried out. A flight qualifying thermal vacuum test is planned within the week.

The proportional counter will be filled with a 90% Xenon--10% Methane mixture for the actual flight, which is planned for late June from Palestine, Texas. Extensive use will be made of Prof. Lawrence Peterson's gondola electronics, radio transmitting system, and ground based data-handling system. Objectives of the flight, besides the engineering test of the proportional counter systems, call for an observation of the energy spectrum of the discrete X-ray sources Cyg Xr-1 and Xr-2 and a measurement of the efficiency of anticoincidence shielding at balloon altitudes.

Gamma-Ray Detector

A ruggedized ceramic photomultiplier tube was evaluated for use in the gamma-ray detector (Fig. 3). Tests included resolution, drift stability, temperature, vibration, inherent radioactivity, and effect of a magnetic field. The tube was returned to the manufacturer after becoming erratic.

Other accomplishments in this area include a determination of the net alpha particle spectrum of Am-241, evidence that this spectrum has a thermal gain dependence different from that of gamma rays which compromises its usefulness

as a calibration reference, and a comparison of several materials for optically coupling the crystal to the photomultiplier tube.

Design work on the prototype of a complete detector, possessing a separated plastic anticoincidence mantle around a 3 x 3 in. NaI (Tl) crystal has been completed, and fabrication will start next month. The configuration is based on a breadboard developed by L. Peterson's group at UCSD.

Electronics

A breadboard instrument, designed and fabricated by Analog Technology Corporation, was tested extensively (Figs. 4 and 5). Besides a 256-channel analog-to-digital converter, it includes amplifiers, shield coincidence circuitry, high-voltage supply, monitoring scalers, and digital readout logic. Overall performance is very good.

Automated Data Processing System

In March 1967, a decision was made to define an automated data processing system that would serve as a ground support equipment system for scientific evaluation and calibration of gamma ray prototype and flight spectrometers. A small, on-line computer and spacecraft data simulator were to serve as a basis for the GSE. Technical information and cost estimates were obtained for various off-the-shelf components. A feasibility study was conducted, followed by consideration of alternative system concepts. A tradeoff study was then made with the purpose of coming up with the optimum system, both in terms of achieving the desired objectives and total cost. Such an optimum system was defined.

The next milestone consisted of generating an Automated Data Processing Equipment (ADPE) Acquisition Plan for internal use by JPL. The plan has been approved by JPL and submitted to NASA for approval.

During the preparation of the ADPE plan and its approval, the GSE system was modified slightly. The system presently consists of a basic computer, teleprinter, paper tape punch and reader, magnetic tape transport, and PCM translator. The spacecraft data simulator will be deferred until a specific gamma ray mission can be identified.

Future milestones consist of issuance of the requests for procurement (July 5, 1967) and delivery of the equipment (October 15, 1967). The target date for equipment readiness and operation is January 1, 1968.

PUBLICATIONS DURING REPORT PERIOD

Open Literature

1. Dolan, J. F., "The Polarization of Celestial X-Rays," Space Science Reviews, Vol. 6, 579-601, 1967

ANTICIPATED PUBLICATIONS

None.

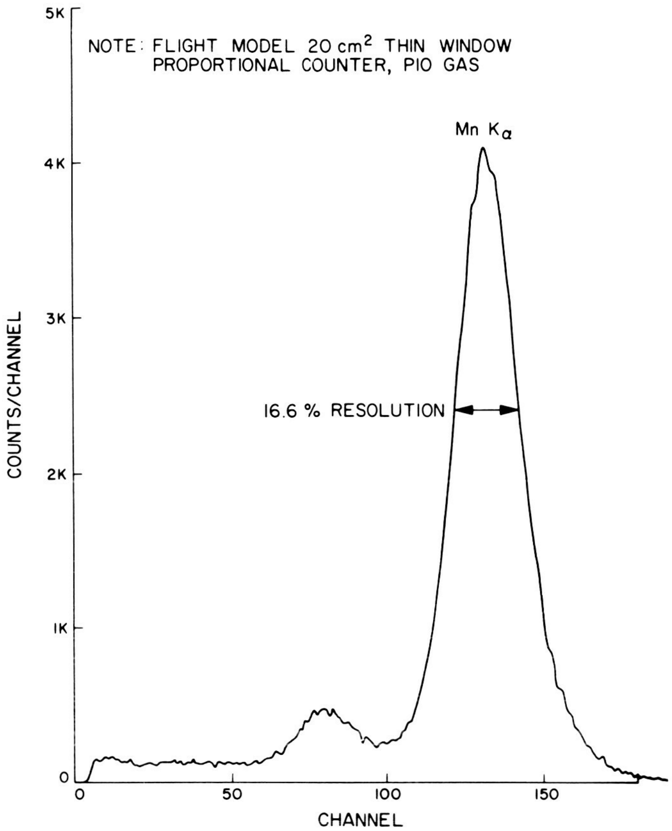

Fig. 1. X-ray spectrum for Fe^{55}

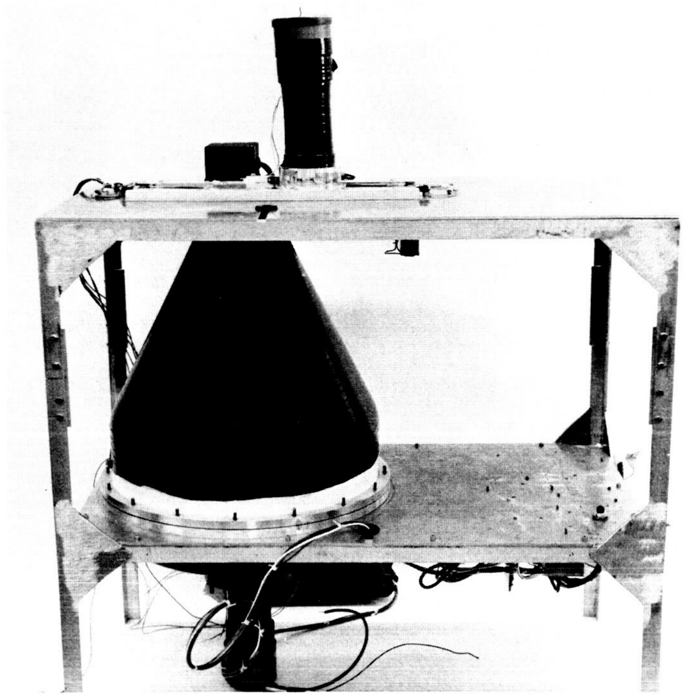

Fig. 2. Proportional counter, actively shielded X-ray detector

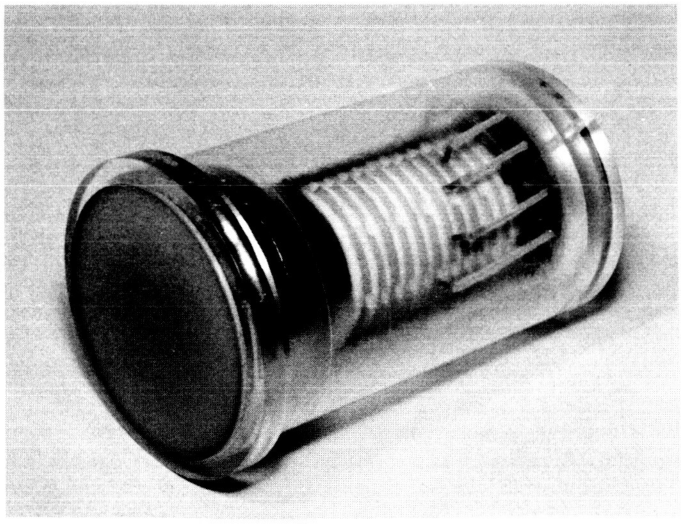

Fig. 3. RCA ceramic photomultiplier tube

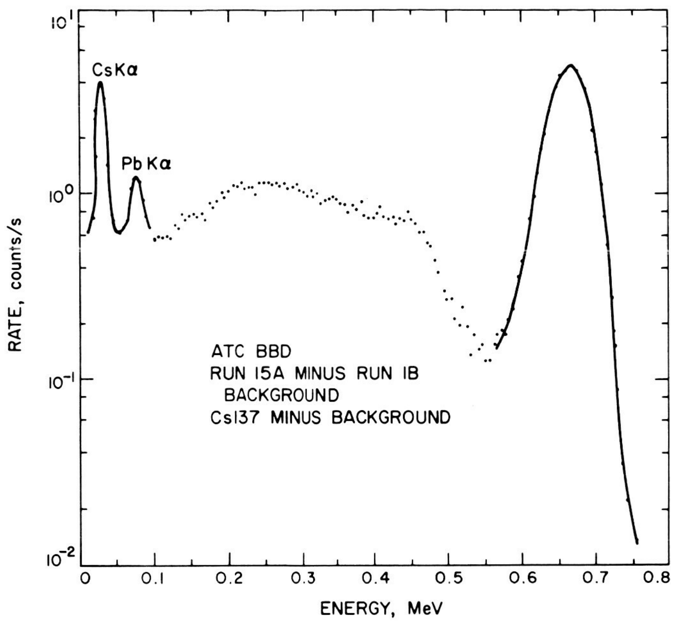

Fig. 4. Spectrum of C_s-137 with ATC breadboard

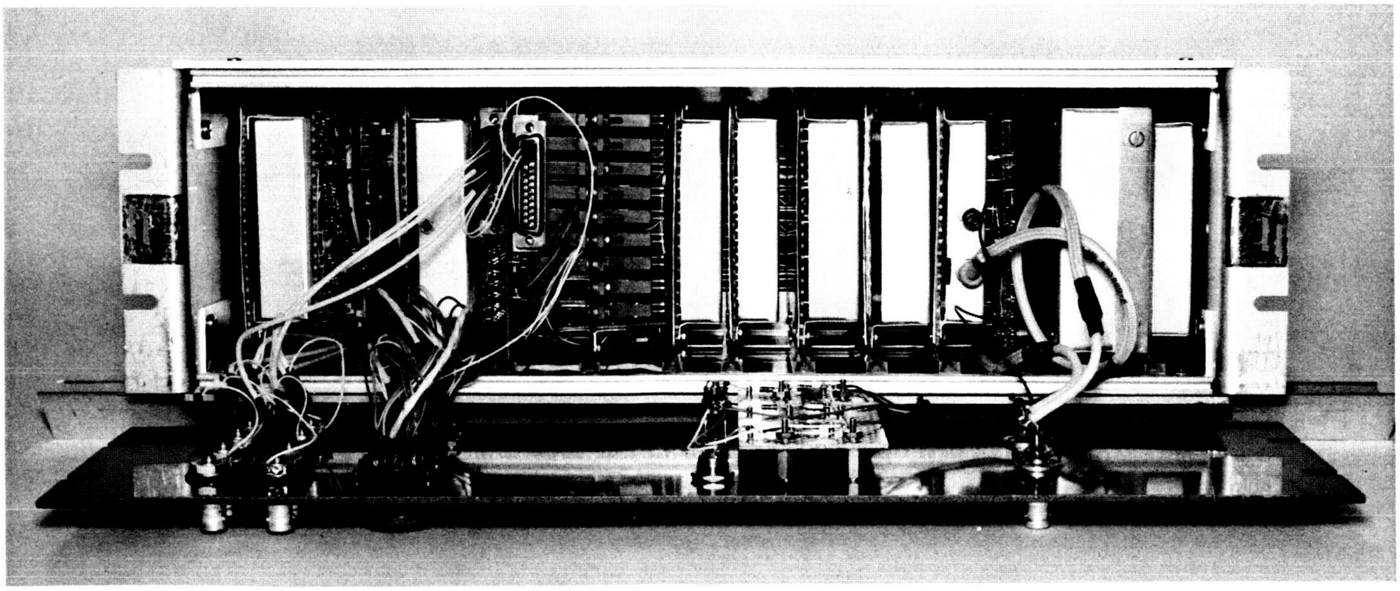

Fig. 5. Gamma-ray pulse height analyzer breadboard (ATC)

GEOSAMPLING (GEOLOGICAL SAMPLING)

NASA Work Unit 185-37-20-14-55
JPL 383-31701-2-3220
E. A. Howard

OBJECTIVE

The objective of the geosampling effort is to develop devices capable of delivering to analytical instruments suitable lunar and planetary surface or subsurface samples representative of the location from which the samples were obtained.

SAMPLER DEVELOPMENT

Three general classes of samplers have evolved, namely, (1) hard rock samplers such as drills, (2) selective particulate samplers which are generally sieve-like devices that acquire material through small holes or slots, and (3) bulk particulate samplers such as the Surveyor backhoe surface sampler.

Information from Surveyors I and III, the Lunar Orbiters, and Mariner IV indicate that both Mars and the moon apparently have an abundance of surface particulate material. Thus, our in-house efforts were increasingly directed toward the development of particulate samplers while our out-of-house efforts continued along the line of drill developments and other means of fragmenting rock.

Contractual Activities

Most geological instruments considered for unmanned missions require pulverized rock samples, the source of which may be (1) fragmented bedrock, (2) existing fine, surface or subsurface particulates, or (3) the larger of the surface or subsurface particulates (i. e., pebbles) freshly fragmented by a pebble crusher of some sort. Generally, the particle-size requirements for geological instruments are not critical as long as the larger particles do not exceed 1/2 to 1 mm in size and are not too abundant in quantity. However, two geological instruments which have been brought to an advanced state of development do have special particle-size requirements. These are the X-ray diffractometer (XRD) for which 1 to 20 μ sizes are preferred and the petrographic microscope for which 50- to 300-μ sizes are desired, with none over 300 μ and not more than 15% under 50 μ. Due to these requirements, the Hughes Tool Co.[1] and the National Research Corp.[2] were contracted (FY 1966 funds) to investigate particle-size control in the fragmentation of bedrock by special drilling and grinding techniques, respectively. Both have had no difficulty in supplying samples for the XRD since normal techniques tend to produce the fine particles needed, but neither contractor could develop fragmenting methods which would produce 50 to 300-μ size particles that would not also produce too many of the unwanted larger and smaller sizes. The conclusion reached is that samples for the petrographic microscope will have to be size-sorted and some of the sample discarded regardless of how the sample is obtained. Figure 1 shows particle-size distributions of Little Lake basalt fragmented by various methods.

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[1] Contract 951398, December 1965 - March 1967.
[2] Contract 951422, January 1966 - January 1967 extended through June 1967.

The first phase of another contract (Contract 951480 with the Hughes Tool Co.) was completed during this reporting period. It involved the testing of a JPL rotary impact drill breadboard with an axial vibratory transport system within the drill stem as shown on the left in Fig. 2. The drilling and transport functions are performed separately. After rotary-impact drilling to preset increments of depth, the drill lifts off the bottom of the hole so that the impacting mechanism can produce sufficient axial acceleration of the drill stem to cause the drill cuttings to jump up from one step to the next within the drill stem, thus, achieving vertical transport. Modifications by Hughes Tool Co. have improved its performance and it now satisfactorily transports drill cuttings. However, sample acquisition in rubble remains poor and attempts at improvement by adding a conical abrading sieve collector as shown on the right were unsuccessful. The cone collects sample but, upon liftoff for transport, the sample is lost back out through the holes in the sieve due to the impacting required for transport. Hughes is now working on the second phase of the contract: the design, fabrication, and testing of a rotary impact drill sampler breadboard with a helical screw conveyor transport within the drill stem. Completion is scheduled for November 1967.

In-House Activities

A deep subsurface sieve cone sampler breadboard, shown in Fig. 3, was fabricated and tested. It can penetrate 2 ft into sand and rubble soil models collecting about 500 g of sample in 30 min; it can also sample in consolidated models of low compressive strength. Additional testing was accomplished on the batch drum sampler shown in Fig. 4. It uses high-pressure gas for soil transport, hence, is independent of the planetary atmosphere (i.e., can operate in lunar vacuum) and will convey the sample over considerable distances (50 ft to date). In fact, tests to determine the capability of the high-pressure gas transport indicate reasonable ranges of 1000 ft through 3/16-in.-ID hose and 500 ft through 1/8 in.-ID hose. The rock (pebble) crusher shown in Fig. 5, previously described, was built and tested. Test results are shown in Fig. 1. A soil auger bulk particulate sampler breadboard was designed and is being fabricated, see Fig. 6. A Hughes Aircraft "Surveyor Surface Sampler" was acquired and is being readied for field testing. Figure 7 lists the samplers presently under development on the "Geosampling" and "Biosampling" tasks.

FUTURE ACTIVITIES

It is expected that all breadboard sampler concepts presently considered promising will have been designed and constructed by early FY 1968. Later in FY 1968 it is anticipated that they will be laboratory performance-tested and certain ones field-tested (by Philco-Ford). On the basis of these tests it is proposed that certain of these samplers undergo engineering model design to establish design parameters such as weight, size, and volume.

A milestone chart indicating the schedule established for this work unit is shown in Fig. 8.

PUBLICATIONS DURING REPORT PERIOD

Contractor Reports, Interim, and Final

1. Froebel, R.C., Parametric Study for Lunar and Planetary Geosampling Drill, Hughes Tool Company, Houston, Texas, Monthly Progress Reports for

December 1966, January 1967, and Final Report dated March 1967. JPL Contract No. 951398.

2. Barnard, L. H., Development Program of a Lunar and Planetary Geosampling Device, Hughes Tool Company, Houston, Texas, Monthly Progress Reports for December 1966, January, February, March, April, May 1967, and Final Report for Phase I dated April 1967. JPL Contract No. 951480.

ANTICIPATED PUBLICATIONS

None.

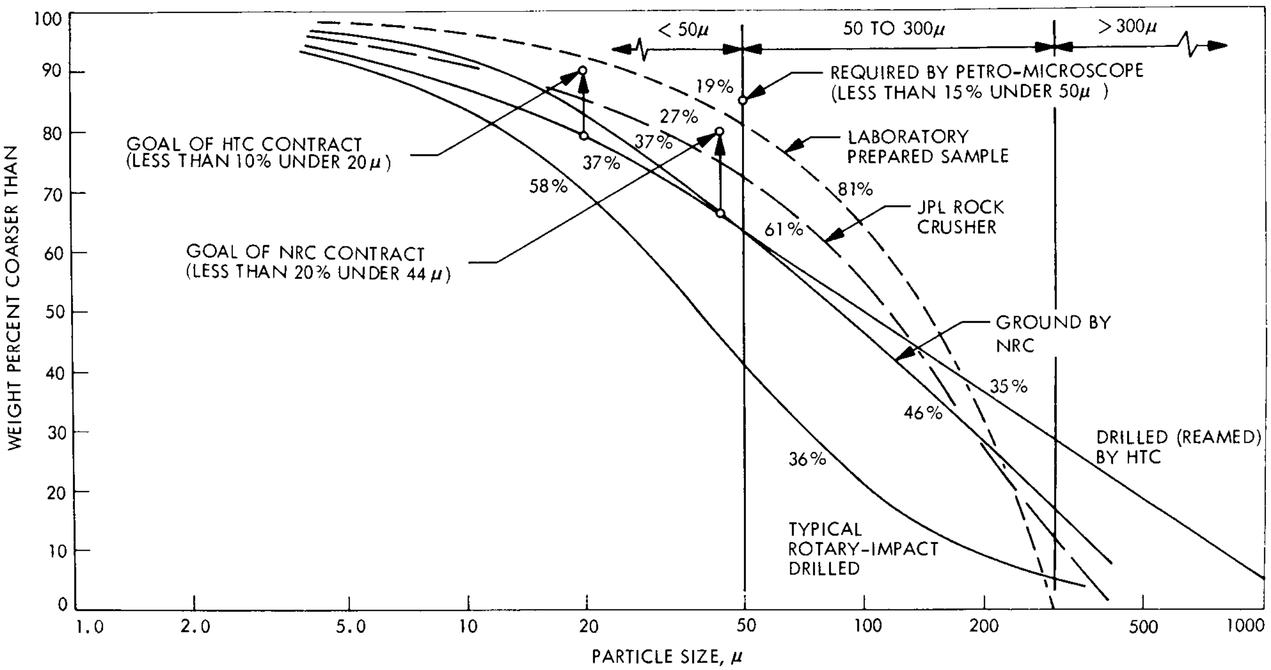

Fig. 1. Particle-size distributions for Little Lake basalt fragmented by a variety of methods

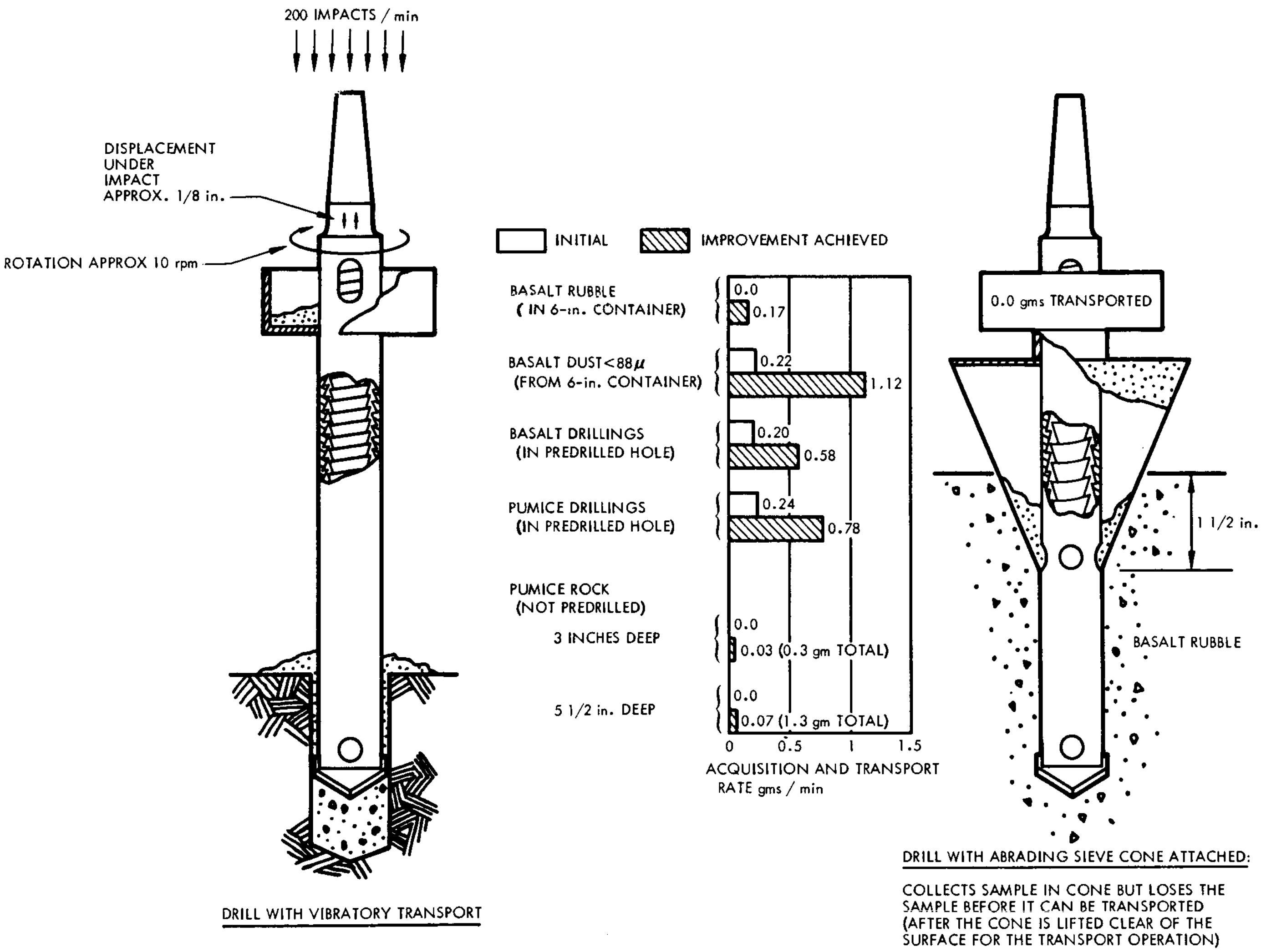

Fig. 2. Test results of JPL rotary impact drill breadboard model A-1 with axial vibratory sample transport

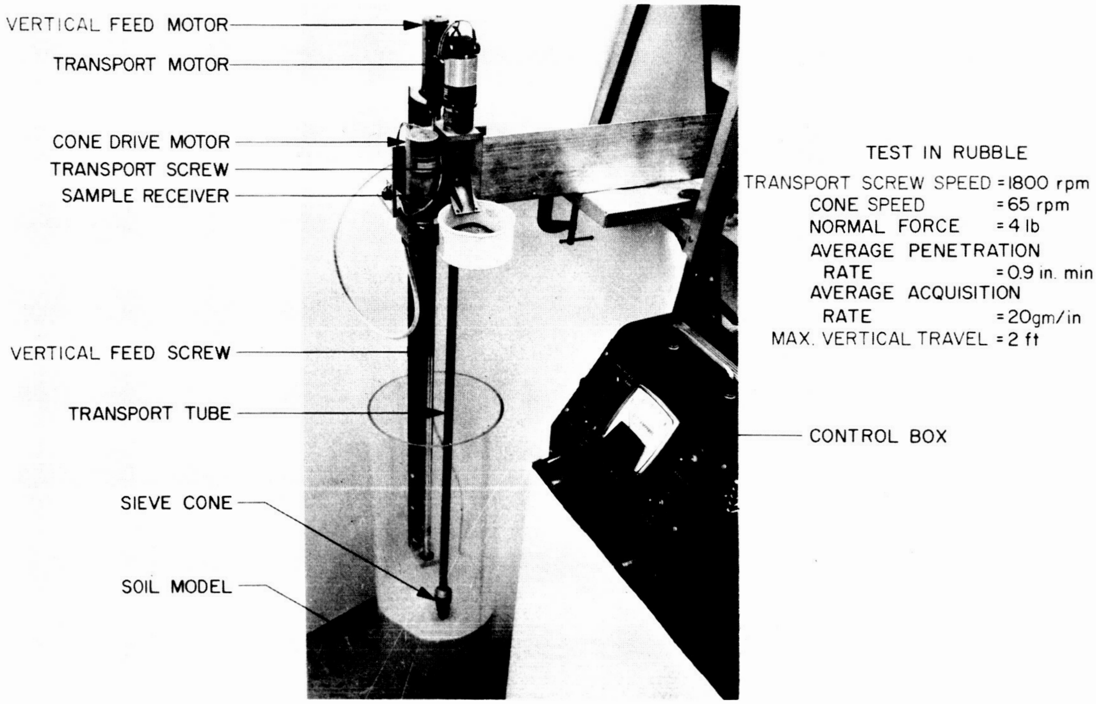

Fig. 3. Deep subsurface sieve cone sampler

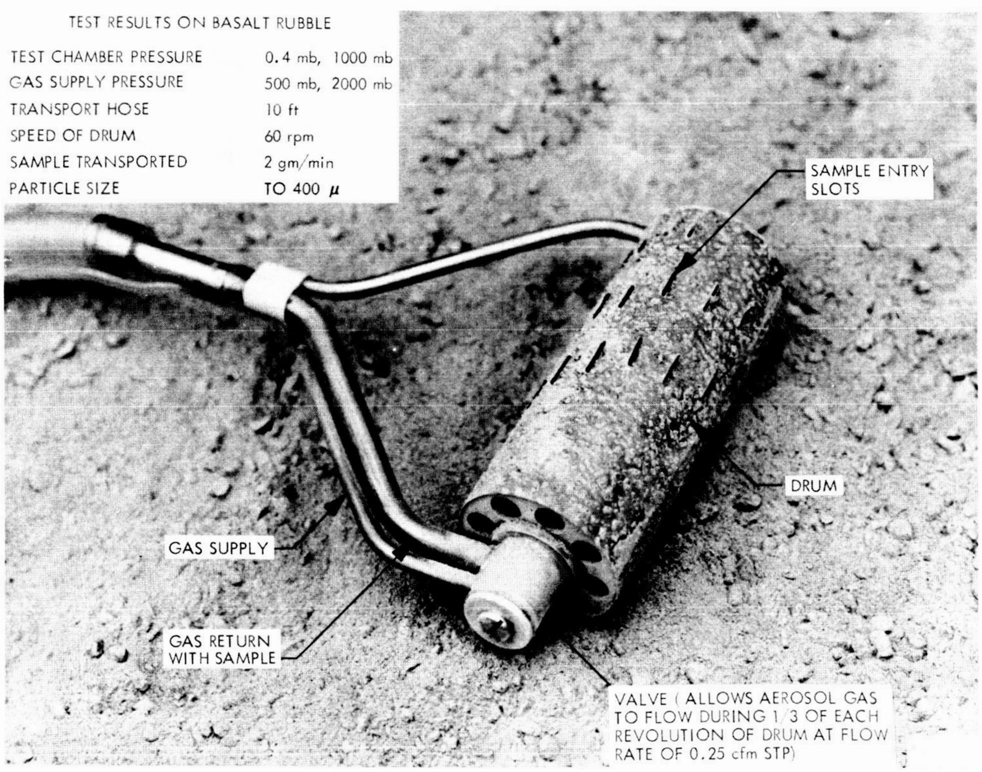

Fig. 4. Abrading drum sampler with batch aerosol transport

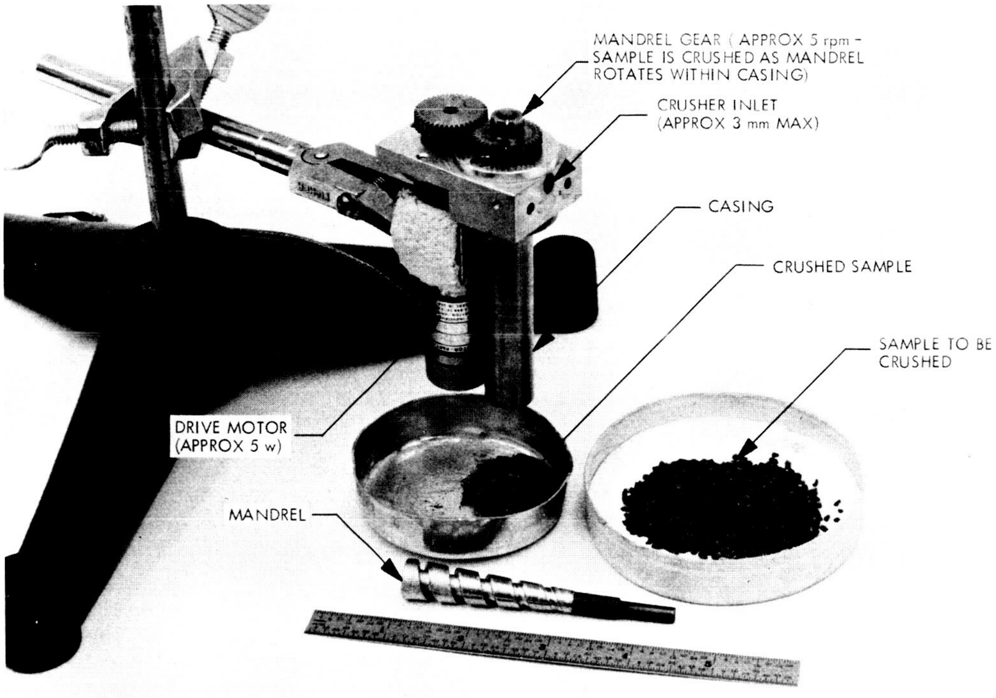

Fig. 5. Rock crusher

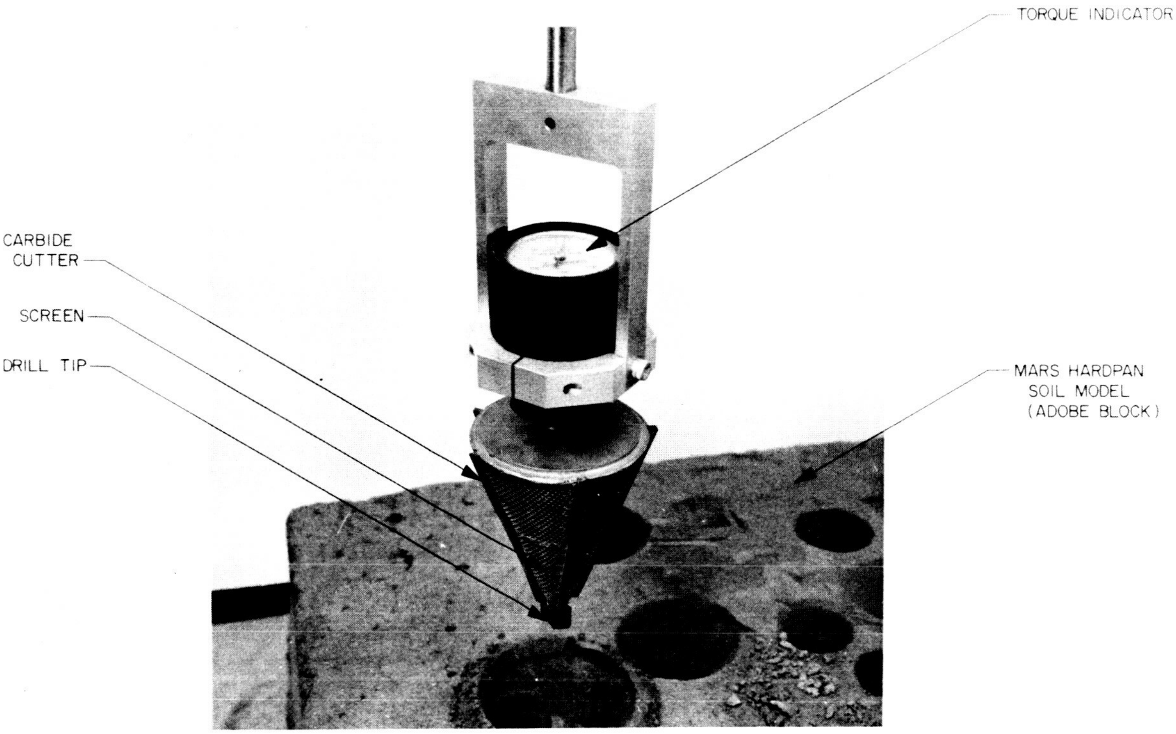

Fig. 6. Abrasive sieve cone with cutter blades

SAMPLER		BREADBOARD STATUS			ORDER OF COMPLEXITY	USE	
		DESIGN	BUILT	TESTED		GEO	BIO
HARD ROCK SAMPLERS	1. UNCASED DRILL (HTC)				4	√√	—
	2. CASED DRILL (JPL)	(BEING REDESIGNED)			5	√√	—
SELECTIVE PARTICULATE SAMPLERS	3. SHALLOW ABRADING SIEVE CONE (PHILCO-FORD)				3	√√	√√
	4. DEEP ABRADING SIEVE CONE (JPL)				3	√√	√
	5. ROTATING DRUM SIEVE (JPL)				2	√	√√
	6. HELICAL CONVEYOR - DRILL TIP (JPL)				2	√√	√
	7. HELICAL CONVEYOR - PLAIN TIP (JPL)				1	√√	√
	8. AEROSOL ACQUISITION (LITTON)				2	—	√√
	9. ROTATING WIRE BRUSH (PHILCO-FORD)				5	√	√√
	10. ROTATING BATCH DRUM SIEVE (JPL)				3	√√	√√
BULK PARTICULATE SAMPLERS	11. AUGER (JPL)				3	√√	√√
	12. BACKHOE (HAC/JPL)	(TO BE REDESIGNED)			5	√√	√√
	13. DRAGLINE SCOOP (JPL)				2	√	√√

1 - SIMPLE
5 - COMPLEX

√√ GOOD
√ FAIR
– POOR

Fig. 7. Developmental status of sampler breadboards

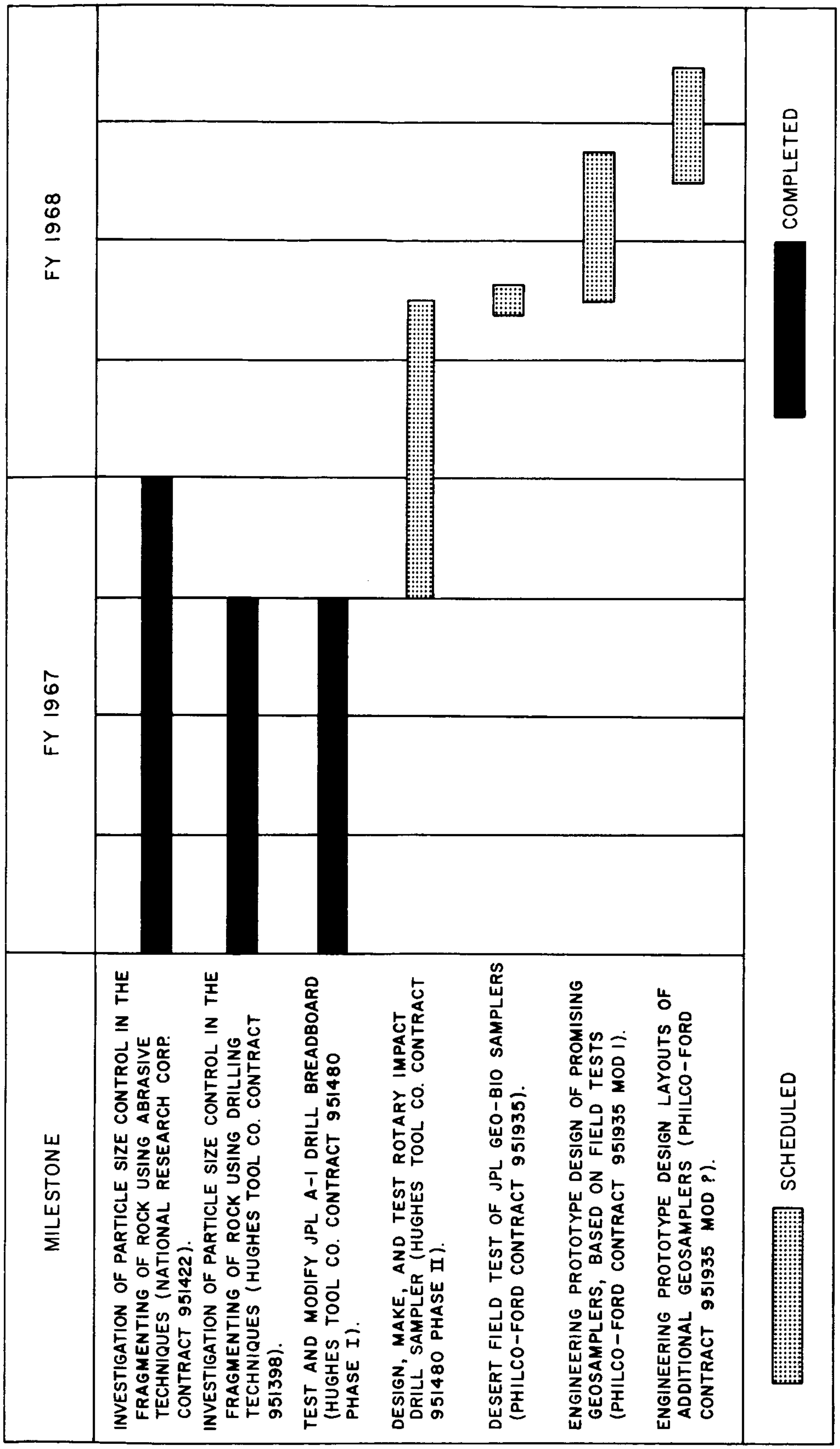

Fig. 8. Milestone chart for geosampling task

MICROWAVE SURFACE PROPERTIES STUDIES

NASA Work Unit 185-37-24-01-55
849-34-20-10-55
JPL 383-30401-2-3250

W. E. Brown, Jr.

OBJECTIVE

The long-range objective of this work unit is to provide microwave instrumentation and data interpretation techniques for the study of planetary surfaces. The immediate objectives are (1) to obtain factual information about the radar echo behavior as a function of altitude for altitudes in excess of 150 km and (2) to reduce the ambiguities in echo interpretation by comparing the echoes obtained from a known target area with the theoretical echo derived from the measured surface characteristics.

PROGRESS

The 1000-MHz radar was flown on the NASA Convair 990 on February 16 and 17, 1967. The target areas included Salton Sea, Death Valley, Sonora Pass, Northern California farm land and ocean areas. Signals were obtained at altitudes of 5 and 10 km. The purpose of this flight experiment is to establish "signatures" for distinctly different terrestrial regions. These "signatures" will be used to demonstrate the validity of the analysis methods.

The data reduction of the Aerobee 150 data (acquired May 9, 1966) and the CV 990 data (acquired April 28, 1966) now includes the following software. Digitizing and editing programs are used by the PDP-4 computer to convert the raw data to the IBM 7094 format. Programs have been generated for computing scale factor, removing TACAN interference, averaging the echoes, and accounting for system parameters such as range loss and antenna pattern. The same software will be used in the reduction of the recent CV 990 data (acquired February 17, 1967).

The construction of an L-band (1215 MHz) coherent imaging radar breadboard is continuing. The transmitter is undergoing preliminary testing. It is expected that virtually all the components for the basic system will be delivered to JPL by the end of the 1st quarter in FY 1968. A CV 990 flight test of the breadboard is tentatively scheduled for November 1967. The principal purpose of this instrumentation is to provide a spacecraft radar suitable for the study of the surface of Venus.

PUBLICATIONS DURING REPORT PERIOD

Open Literature

1. Brown, W. E., Jr. "Lunar Surface Surveyor Radar Response" J. Geophys. Res., Vol. 72, No. 2, p. 791-799, January 15, 1967.

ANTICIPATED PUBLICATIONS

JPL Technical Reports

1. Brown, W. E., Jr., et al., Rocket Radar Engineering Report (80% complete).

2. Brown, W. E., Jr., Preliminary Results of the High Altitude Radar Experiment (pending data availability).

MICROWAVE RADIOMETER DEVELOPMENT
NASA Work Unit 185-37-25-01-55
JPL 383-30901-2-3250
F. T. Barath

OBJECTIVE

Under this task, instrumentation is provided for the JPL Space Sciences Division (32) Radio Astronomy effort, and advanced techniques are developed for future spacecraft-borne microwave radiometers.

Specifically, the long-range objectives are:

(1) To design, develop, fabricate, and test high-performance microwave radiometers in the 3-cm to 1-mm wavelength region.

(2) To utilize and evaluate these radiometers in the framework of a ground-based radio astronomy program specifically directed at studying the planets and the moon.

(3) To develop techniques and instrumentation for future spacecraft experiments.

PROGRESS

20- to 24-GHz Variable Frequency Radiometer

The 20- to 24-GHz variable frequency radiometer was tested for long-term performance and extensively calibrated following the Venus observations performed during the previous reporting period. This radiometer has now operated satisfactorily for 9600 h. The system will be installed on a 10-ft antenna and used for atmospheric studies during the next quarter.

18-ft Precision Antenna System

The acceptance tests of the 18-ft precision antenna system revealed an unacceptable subreflector mechanism, which was returned to the manufacturer. After rework and reinstallation, testing revealed that the mechanism still does not fully meet specifications. Although the system is quite usable as is, negotiations are under way with the manufacturer for further improvements. It is anticipated that the antenna will be released for observational use on or about July 1. Figure 1 is a side view of the antenna and its pedestal; Fig. 2 shows the antenna in its servicing position.

Wright Mountain Boresight Transmitter

The Wright Mountain boresight transmitter used to calibrate the 18-ft antenna has been operating satisfactorily. Winter access, however, is extremely difficult, and a remote operation system via RF link will be installed during July. A newly developed geologic fault near the facility might also necessitate relocating it during the summer.

Variable Frequency 8-mm Radiometer

The variable frequency 8-mm radiometer has been in checkout and calibration during the reporting period; it will be mounted on the 18-ft antenna at the beginning of July and used for further antenna calibrations and Venus observations. Figure 3 shows the radiometer during checkout in the laboratory.

8-mm Low-Noise Receiver

The 8-mm low-noise receiver contract with TRG has been slowed down pending delivery of the pump power source. Delivery of the receiver is now anticipated for September 1 at which time it will be incorporated into a radiometer for eventual use on the 18-ft antenna.

Multichannel Radiometer (22-GHz Region)

The new multichannel radiometer in the 22-GHz region is scheduled to be completed on September 1, at which time it will be used for Venus observations on the Goldstone 30-ft antenna. All the components are on order and have been delivered or will be delivered by July 1.

8-mm Interferometer

The 8-mm interferometer progress has been very slow due to the higher priorities being assigned to the above tasks. One of the major components has been damaged in shipment resulting in a 4-mo delivery slip. Work will resume on the system during the first quarter of FY 1968.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

JPL Technical Memorandums

1. Barath, F. T., A Low-Noise Tunable 8-mm Radiometer System, Technical Memorandum, tentative date October 1, 1967.

2. Barath, F. T., A Multichannel Radiometer in the 13-mm Region, Technical Memorandum, tentative date October 1, 1967.

JPL SPS Contributions

1. Kellner, M. L., "Precision 18-foot Antenna and Calibration Facility" (provisional title), tentative date September 1, 1967.

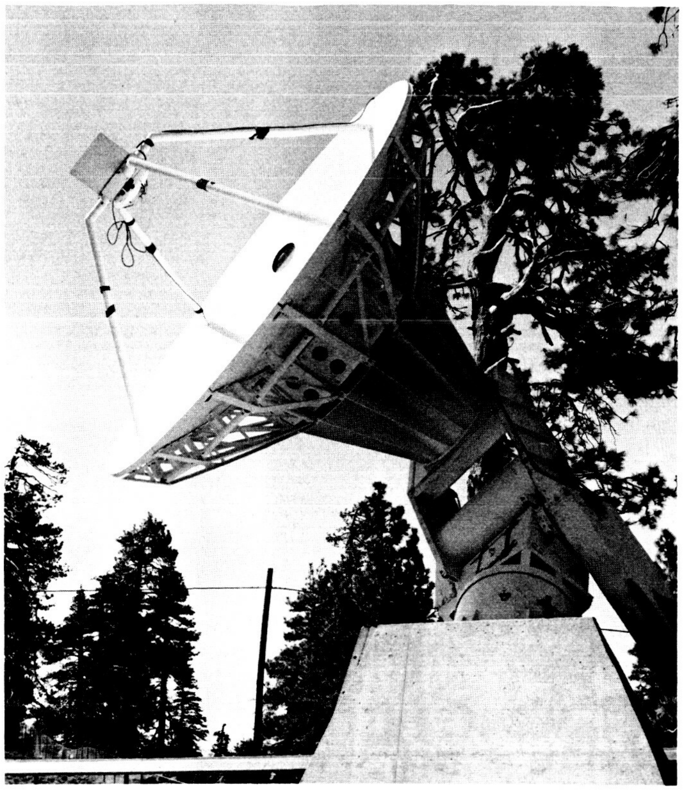

Fig. 1. Precision 18-ft antenna on Table Mountain

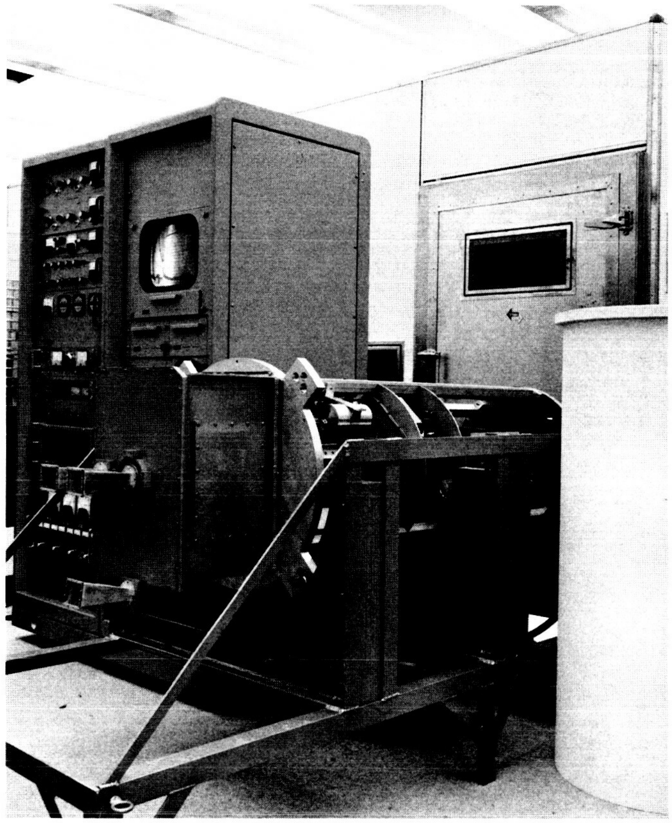

Fig. 3. Variable position 8-mm radiometer system (electronics rack at left; antenna portion at right)

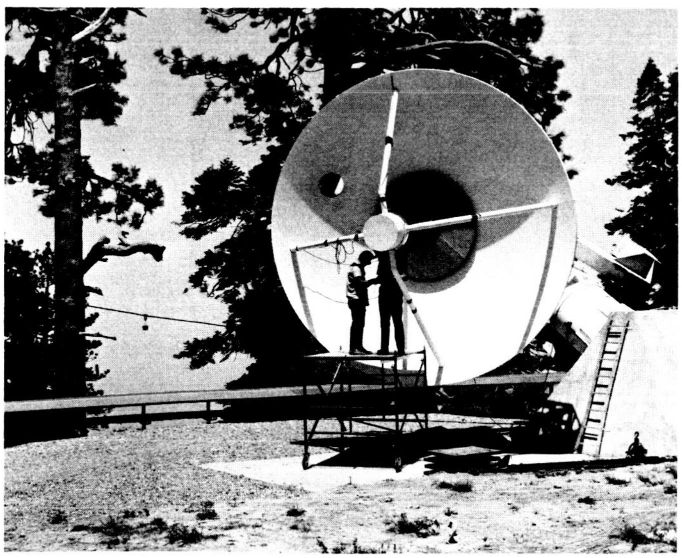

Fig. 2. Precision 18-ft antenna in servicing position

MASS SPECTROMETRY

NASA Work Unit 185-37-26-01-55
JPL 383-31001-2-3260
383-31002-2-3220

C. E. Giffin
H. R. Mertz

OBJECTIVE

The objective of this task has been the development of mass spectrometric instrumentation for the analysis of dense atmospheres (such as those of Mars and Venus) and of tenuous atmospheres (such as those of the moon, Mercury, comets, and the solar wind). The JPL Bioscience Section and Lunar and Planetary Instruments Section both have been active in this work unit. This task in the future will be concerned only with the development of a Mariner 1971 entry mass spectrometer. Technical efforts involving state-of-the-art developments over and above Mariner 1971 requirements will be contained in a new work unit entitled "Advanced Mass Spectrometry."

JPL BIOSCIENCE SECTION ACTIVITY

Planetary Atmosphere Mass Spectrometer

The planetary atmosphere mass spectrometer breadboard has been completed and is presently undergoing a rigorous set of functional tests. A proposal has been submitted to NASA for incorporating the instrument on the Mariner Mars 1971 entry capsule mission for Martian atmospheric analysis. The proposed experimenter team consists of C. E. Giffin as Principal Investigator, F. P. Fanale and L. D. Kaplan as Co-Investigators, and S. Szirmay as Principal Engineer, all of JPL. Professor A. O. C. Nier of the University of Minnesota is an active consultant to the experiment.

Figures 1 and 2 are overall views of the mass spectrometer prior to final assembly. The faraday cage collector shown in the figures has recently been replaced by a sixteen-stage electron multiplier. Figures 3 through 7 show selected portions of the mass range demonstrating the mass resolution and abundance sensitivity capability of the instrument. Figure 3 shows the neon mass spectrum. The resolving power by the 5% definition is 131. Figure 4 shows the argon isotopes exhibiting a resolving power of 151. Figure 5 shows the krypton isotopes exhibiting a resolving power of 91. Figure 6 shows CO_2 plus the doubly ionized krypton isotopes exhibiting a resolving power of 141. Figure 7 shows a complete mass spectrum from M = 11 to M = 90 for a mixture of argon, nitrogen, and carbon dioxide. Due to the narrowness of the mass peaks on the chart, no resolving power measurement was made here. However, it can be estimated to be approximately 130. Because of the wide separation of the peaks afforded by the high mass resolution, isotope peaks at masses 28, 29, 36, 40, 44, 45, and 46 can be accurately measured with ease.

The frequently used term of "mass resolution" only coarsely defines the ability of a mass spectrometer to separate particular mass peaks. The important

practical parameter that must be considered is the "abundance sensitivity" of the instrument, i.e., the level at which a very small peak can be measured accurately next to a very large peak. Here one must consider the shapes of the peaks not just at the 5% level (where resolution is defined) but at the 0.1 or 0.01% level where "tailing" can significantly affect adjacent measurements. In other words, the full dynamic range of a mass spectrometer (5×10^4 in the case of the Mariner Mars 1971 instrument) cannot be achieved at the mass number associated with the limit of its resolution unless there is greater than unit mass separation between peaks. The high resolution of the Mariner Mars 1971 instrument affords the necessary high abundance sensitivity in the low mass region ($M<50$) where "isotopically" interesting gases can be expected in the Mars atmosphere.

Figures 8 and 9 demonstrate the fast scan capability of the mass spectrometer. Figure 8 is a 2.25-s scan of a mixture of krypton and air over the mass range of M = 11 to M = 90. Figure 9 is a 1.50-s scan of a mixture of argon, nitrogen, and carbon dioxide over the mass range of M = 11 to M = 50.

High Sensitivity Mass Spectrometer

Due to major efforts being placed on the planetary atmosphere mass spectrometer, no significant progress has been made on the high sensitivity quadrupole mass spectrometer during the last six months. It is felt that the applicability of the planetary instrument to the impending Mariner Mars 1971 mission justifies this approach. Continuing efforts in this area will proceed under the JPL task entitled Advanced Mass Spectrometry.

Proposed Effort for the Next Six Months

During the next semiannual period, the effort will consist of completion of testing of the scientific breadboard with emphasis on differential pumping of the filament, ion pumping, minimizing magnetic fringe field effects, optimization of the molecular leak inlet system, and electron multiplier detector. Further functional specifications will be written and construction and testing of an engineering model will begin.

LUNAR AND PLANETARY INSTRUMENTS SECTION ACTIVITY

The design and construction of the necessary science breadboard electronics have been completed and separately tested. They have been incorporated into the mass spectrometer system and systems evaluations are in progress. The results to date show that the electronics have performed very satisfactorily.

A vacuum system has been assembled and tested for carrying out the evaluation of electron multiplier characteristics. In particular, the noise levels, saturation currents, and reproducibility of these devices are being studied.

A contract is in the process of being let to construct an engineering model of the double-focusing mass spectrometer. The contract calls for a completion date near the end of the second quarter of FY 1968. The proposed effort is to build an instrument which has been designed to minimize weight, but not at the expense of

structural rigidity. An analysis of the system to determine the effects of fringe fields will be performed and also a low conductance ion source will be designed. A study of the ion beam trajectories in the z direction of the mass spectrometer will be made and a z-axis focusing system will be designed so that it can be added at a later date.

Proposed Effort for the Next Six Months

The primary activity for the next six months will be to complete the engineering model. Associated with this activity will be an in-house worst case analysis of the electronics. Also, it will be necessary to define the instrument interface requirements. Another major area of in-house effort will be directed towards the development of a wide dynamic range (six decades), low noise, wide band (200 μs response time) electrometer. This will require an evaluation of the present state of the art in junction and insulated gate field effect transistors. A study will be made on the possibility of using feedback around the electron multiplier to obtain power law compression of output currents, eliminating data handling problems associated with the automatic range switching electrometer.

Work will continue in the area of electron multiplier evaluations. Also, investigations will be performed to provide a suitable flight-type sample inlet system.

PUBLICATIONS DURING REPORT PERIOD

JPL Technical Memorandums

1. Brereton, R. G., et al, Mission to a Comet, TM 33-297, February 15, 1967.

2. Brereton, R. G., et al, Venus/Mercury Swingby with Venus Capsule, TM 33-332, May 1, 1967.

ANTICIPATED PUBLICATIONS

None.

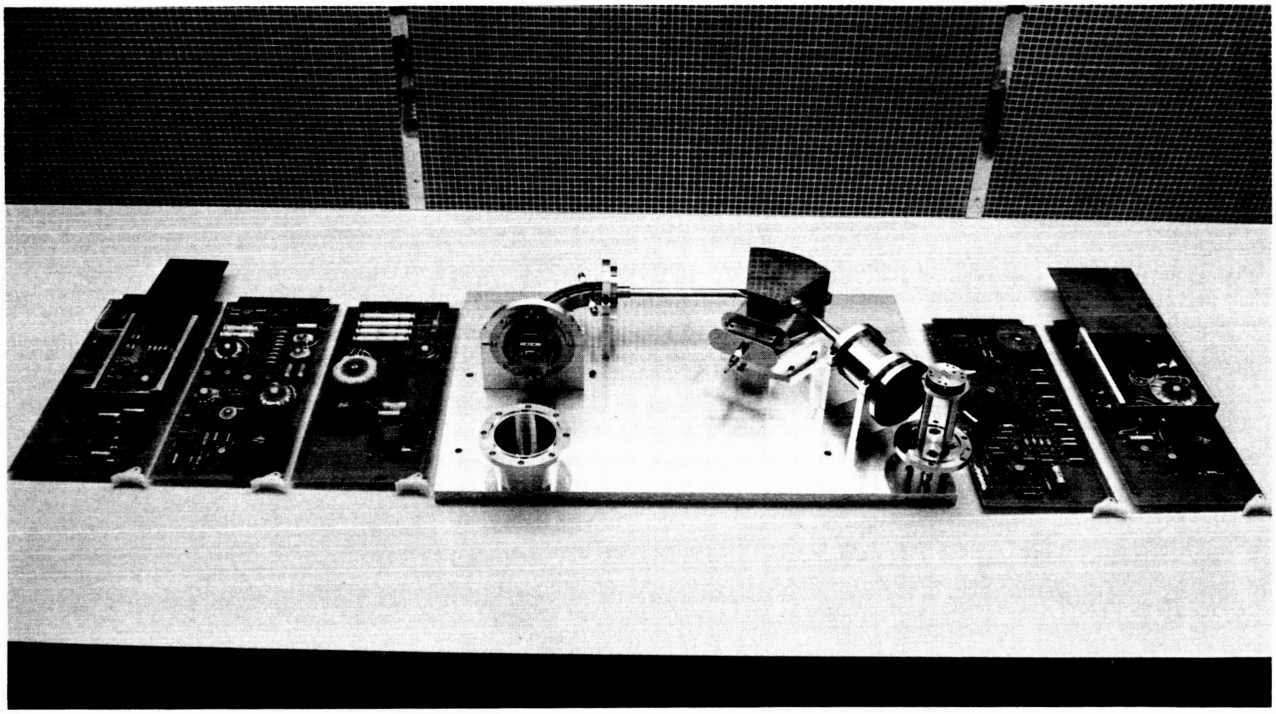

Fig. 1. Double-focusing mass spectrometer (before assembly)

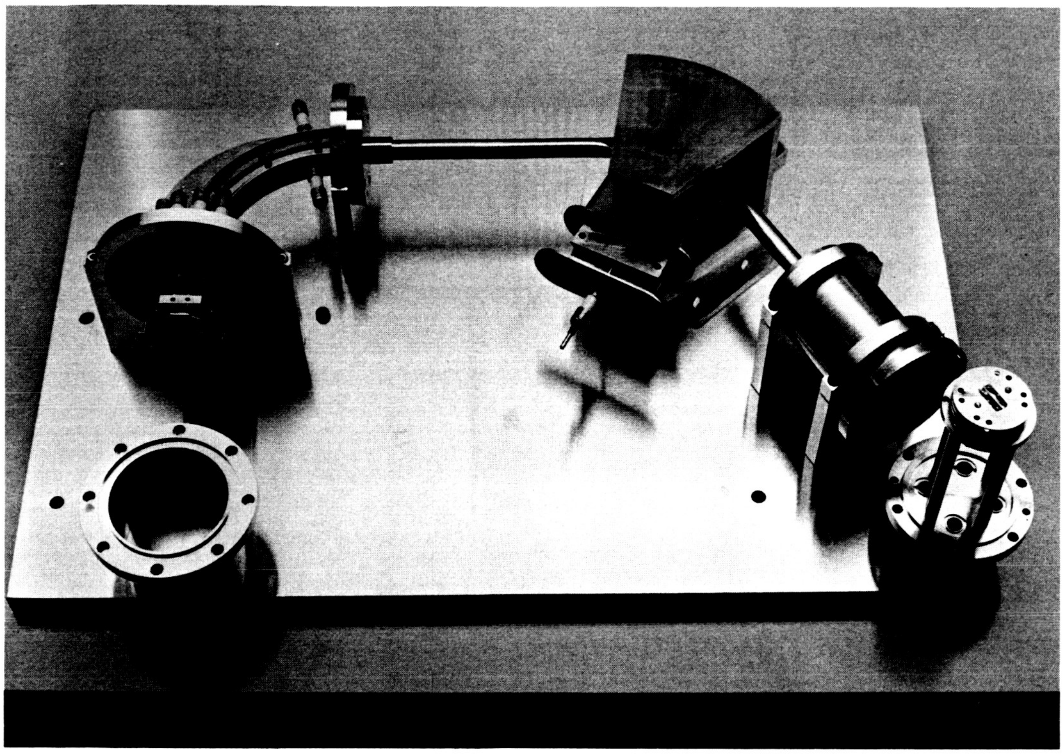

Fig. 2. Double-focusing mass spectrometer (before assembly)

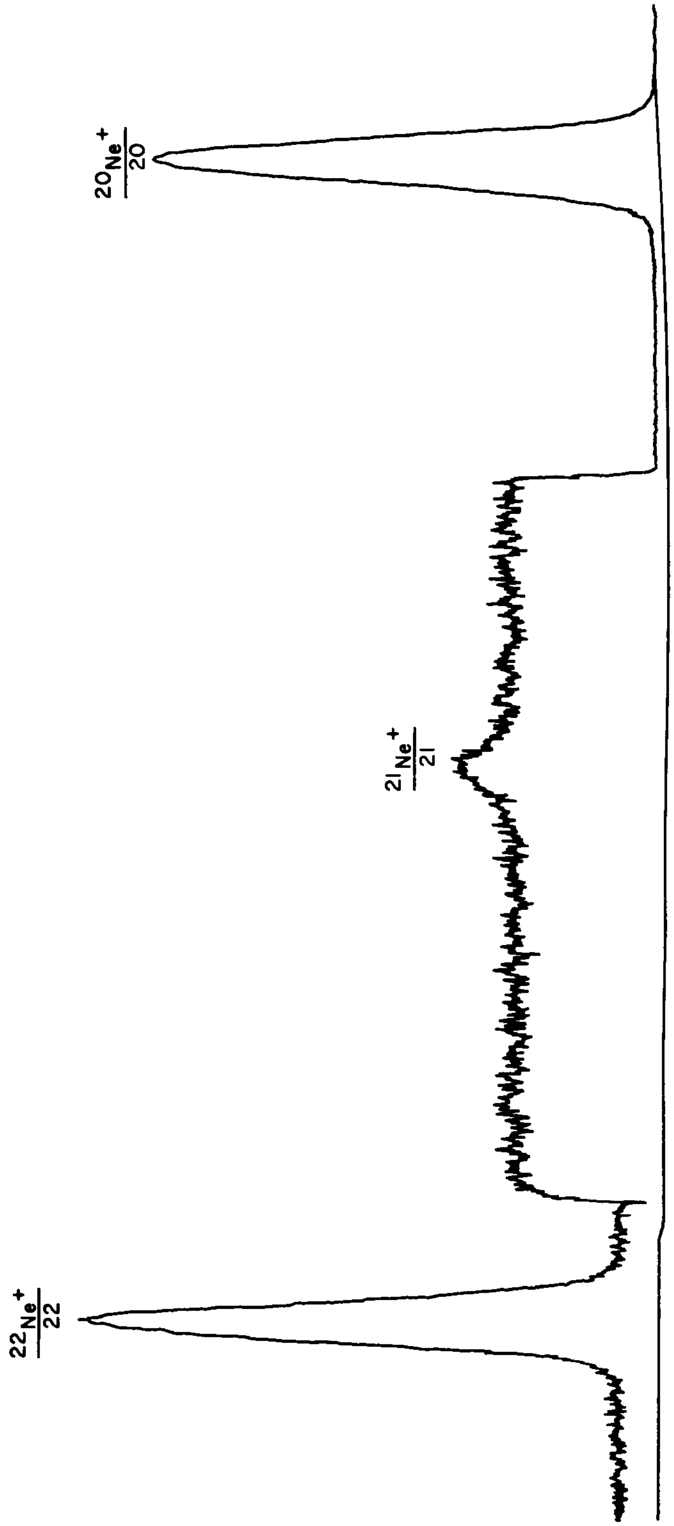

Fig. 3. Neon mass spectra

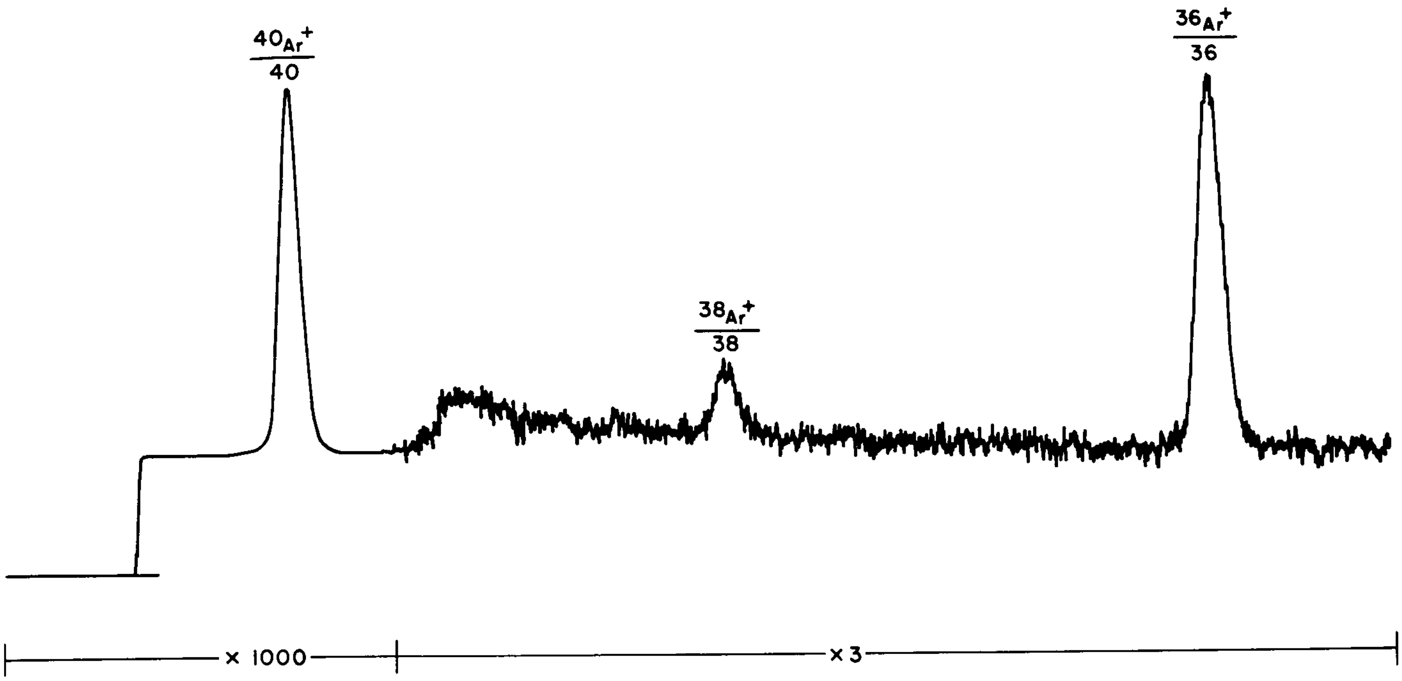

Fig. 4. Argon mass spectra

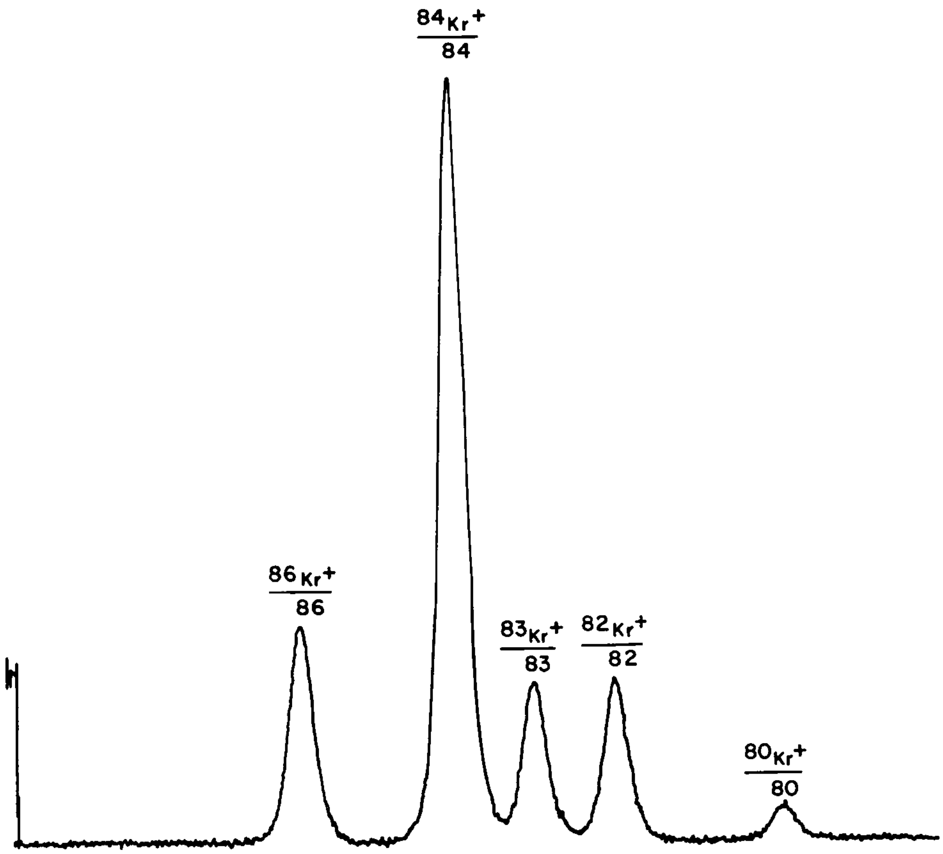

Fig. 5. Krypton mass spectra

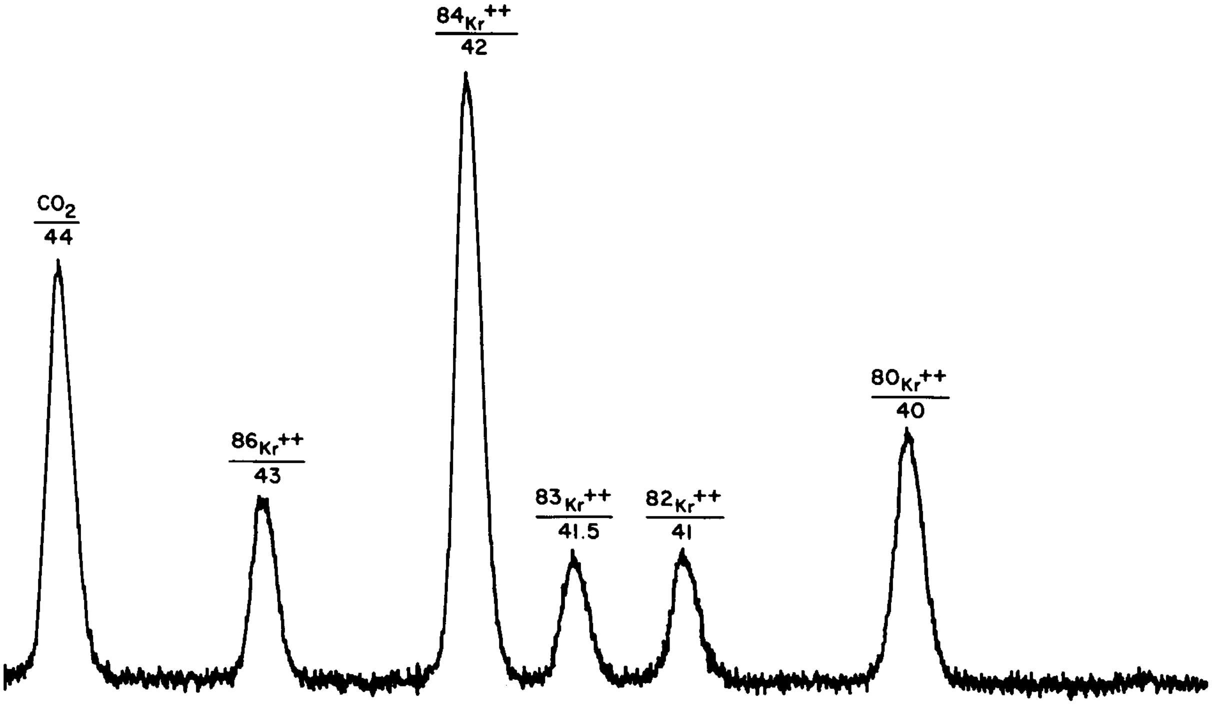

Fig. 6. Doubly ionized krypton mass spectra

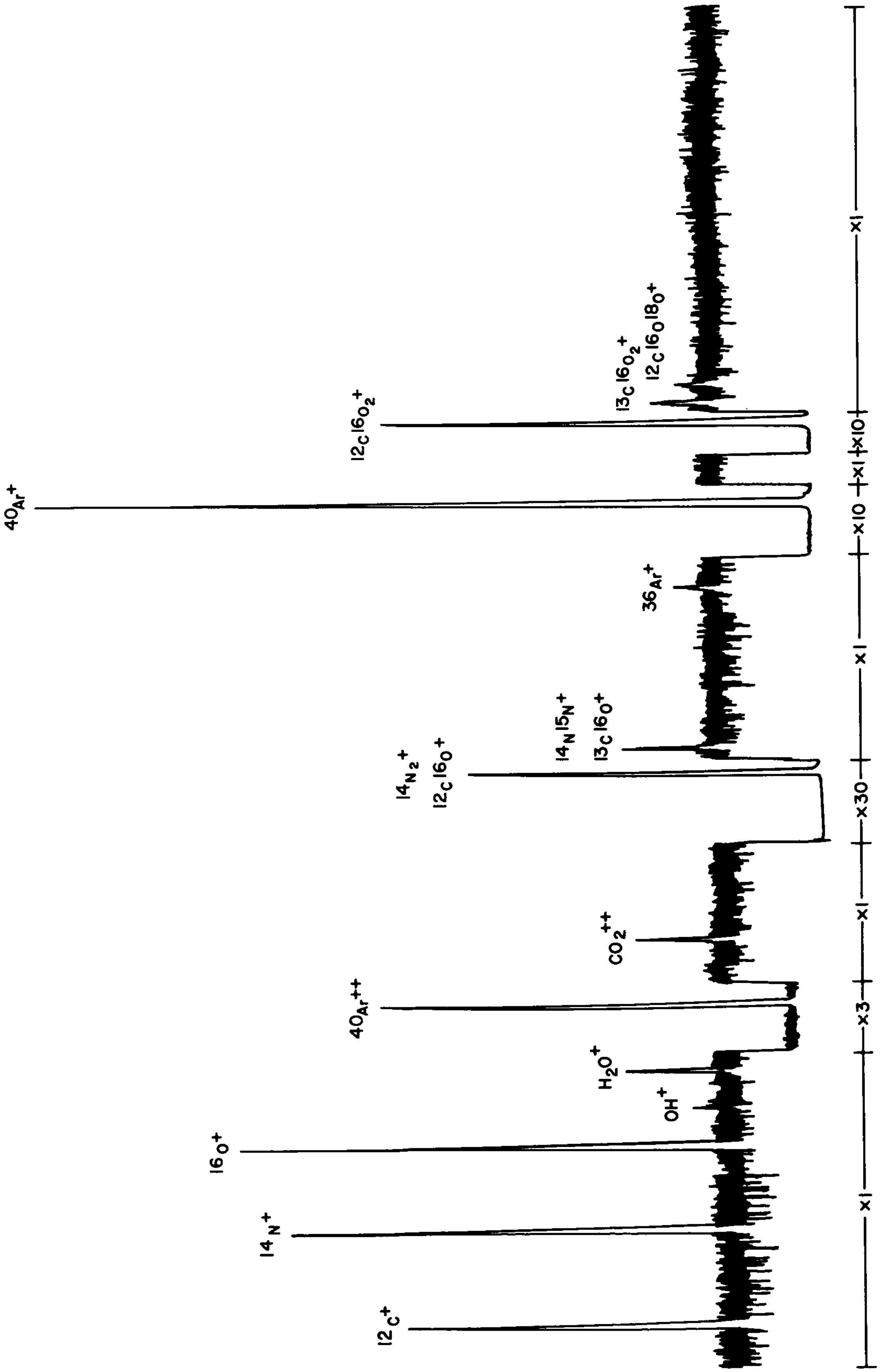

Fig. 7. Mass spectra of mixture of argon, nitrogen, and carbon dioxide

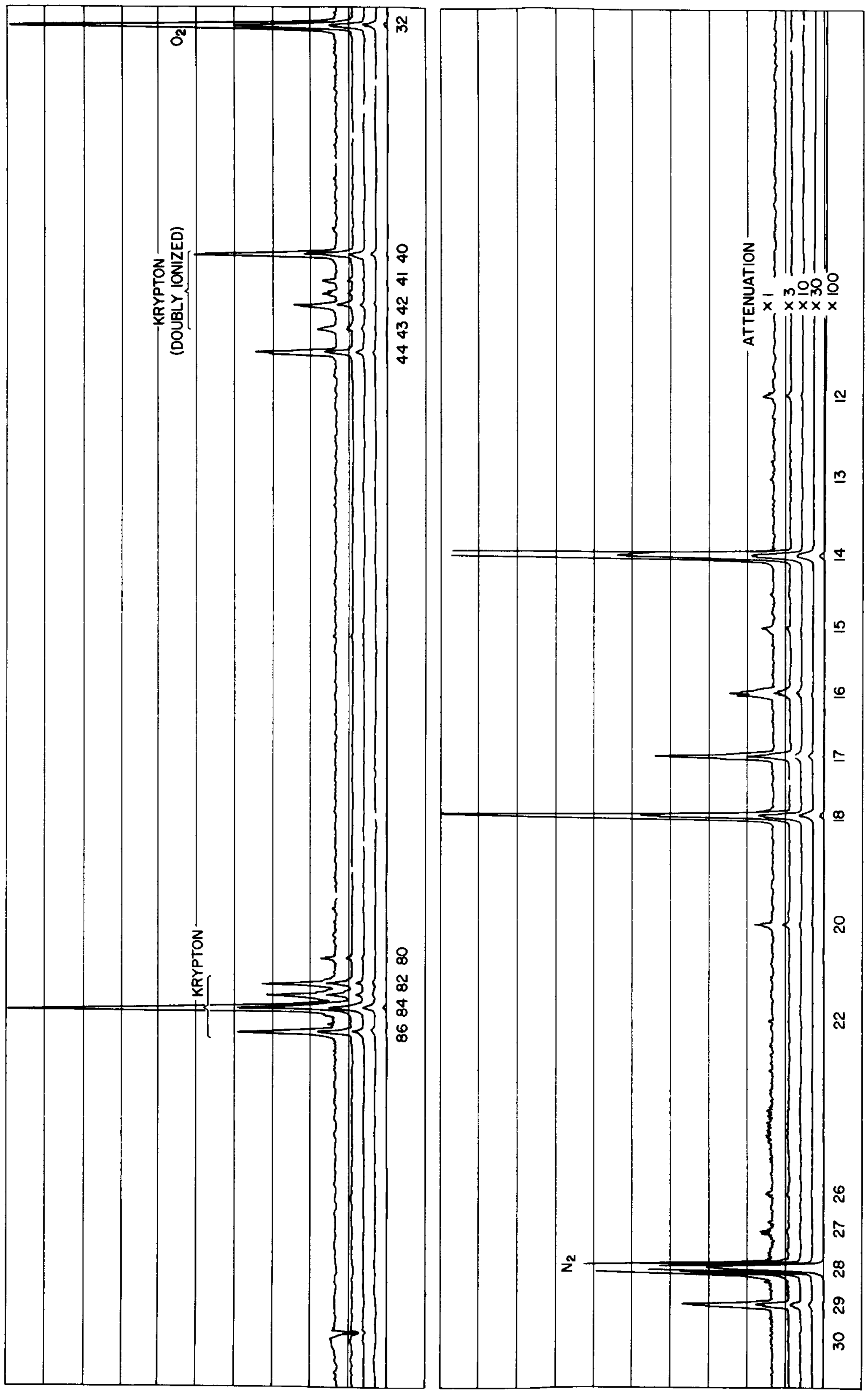

Fig. 8. Scan time of krypton and air. Scan time (M = 12 to 90) = 2 1/4 s

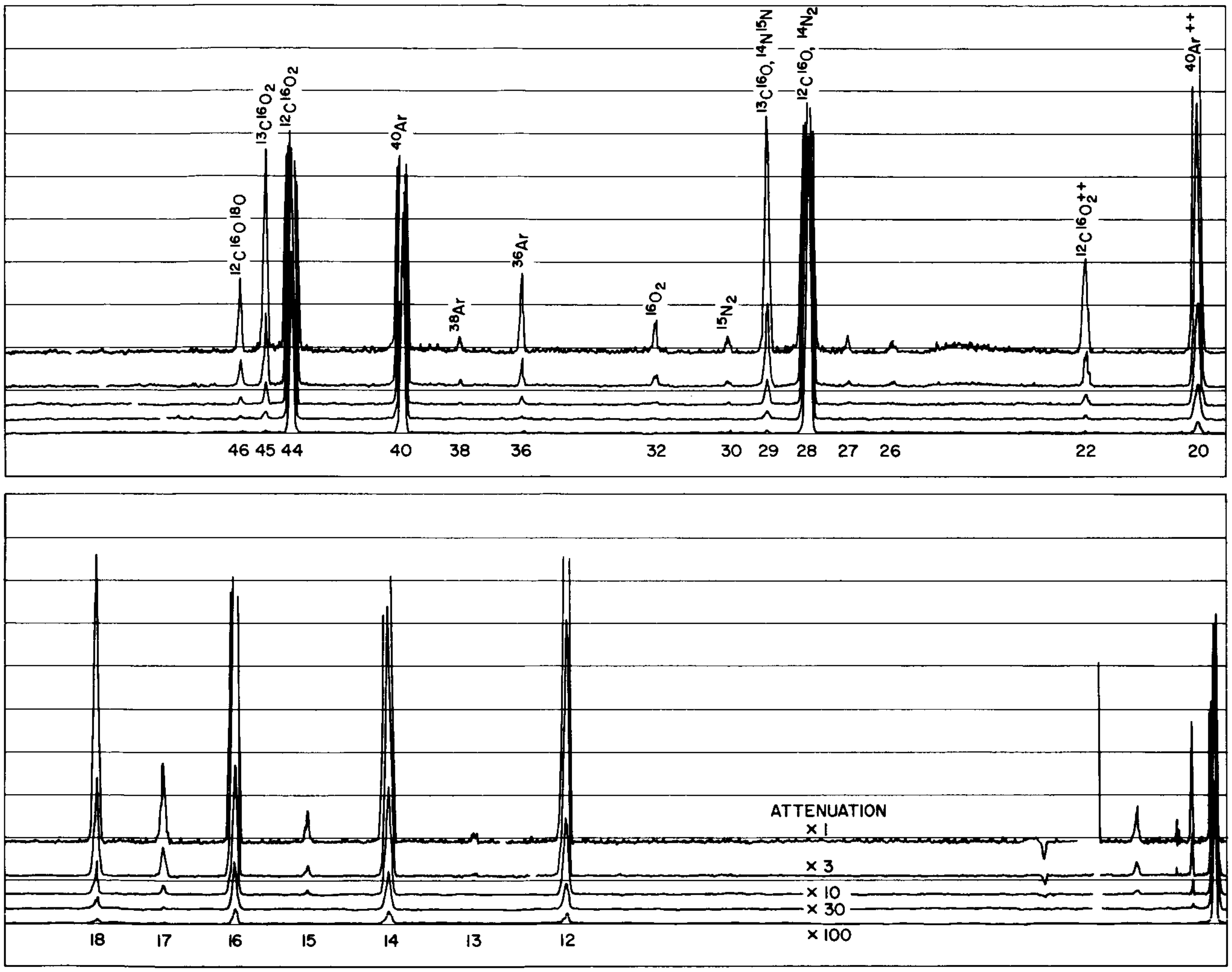

Fig. 9. Scan time of argon, nitrogen, and carbon dioxide mixture. Scan time (M = 12 to 50) = 1 1/2 s

INTERFEROMETRIC INVESTIGATIONS

NASA Work Unit 185-37-26-06-55
JPL 383-30601-2-3250
R. Beer

OBJECTIVE

The long-range objective of this task is to exploit the capabilities of high-resolution interference spectrometers as tools for atmospheric analyses in the field, in the laboratory, and at large telescopes.

PROGRESS

Planetary Interferometers

The Venus spectra produced by the Connes' with the MK II interferometer are now largely reduced. L. D. Kaplan and W. Benedict have made a positive identification of HCL and HF in the Venus atmosphere. L. Gray has analyzed some eighty CO_2 bands seen in these spectra, a number of which have not previously been observed. J. Beckman has concerned himself with the reduction of the Connes Jupiter spectra. His results are reported under NASA Work Unit 185-37-26-16-55, "IR Spectroscopy of Synthetic Atmospheres."

The MK III Planetary Interferometer is now installed on the coudé platform of the 24-in. telescope at Table Mountain, and preliminary observations have commenced. The initial tests on Mars suggest that there is adequate signal/noise in the 3 to 4 μ region to obtain spectral resolutions approaching 1 cm^{-1}, especially if the instrument can be moved to a larger telescope for the 1969 opposition.

The accompanying figures (Figs. 1-5) show the installation at Table Mountain and some of the test data taken to date.

The next year will be spent obtaining experience using the instrument on a variety of astronomical objects. In addition to Mars, attempts will be made to obtain spectra of Mercury, Venus, and Jupiter, to commence the compilation of a solar and lunar atlas for our wavelength regions (largely for comparison and calibration purposes), and to make preliminary observations of some objects of unique interest in collaboration with H. Spinrad of the University of California, Berkeley. The entire program will, as far as possible, be made complementary to that of P. and J. Connes in France so that our data may add constructively to, rather than compete with, theirs.

R. H. Norton's rewritten computer program for the analysis of the interferograms is now in working order. It permits an increase in the speed of reduction by a factor of about 100. Not only is the improvement significant from the point of view of cost reduction, but also the much shorter reduction times will be a great aid during observation runs.

A semidigital 1000-point spectrum analyzer has been acquired for real-time reduction of the interferograms, enabling us to ascertain the basic instrumental

performance on the spot, although at a modest resolution. It has proved invaluable for installing and aligning the MK III at Table Mountain Observatory.

Far Infrared Interferometer

The urgency of the planetary interferometer program has resulted in there being no activity with this instrument during the report period.

PUBLICATIONS DURING REPORT PERIOD

Open Literature

1. Beer, R., "Fourier Spectroscopy From Balloons," Appl. Opt., 6, 29, 1967.

2. Connes, P., Connes, J., Benedict, W. S., and Kaplan, L. D., "Traces of HCl and HF in the Atmosphere of Venus," Astrophys. J., 147, 1230, 1967.

ANTICIPATED PUBLICATIONS

Open Literature

1. Beer, R., and Cayford, A. H., "An Investigation of a Fundamental Intensity Error in Fourier Spectroscopy," J. de Phys., 1967 (in press).

2. Beer, R., "A Balloon-Borne Michelson Interferometer for Solar Spectroscopy in the 10-100 Micron Region," J. de Phys., February 1967 (in press).

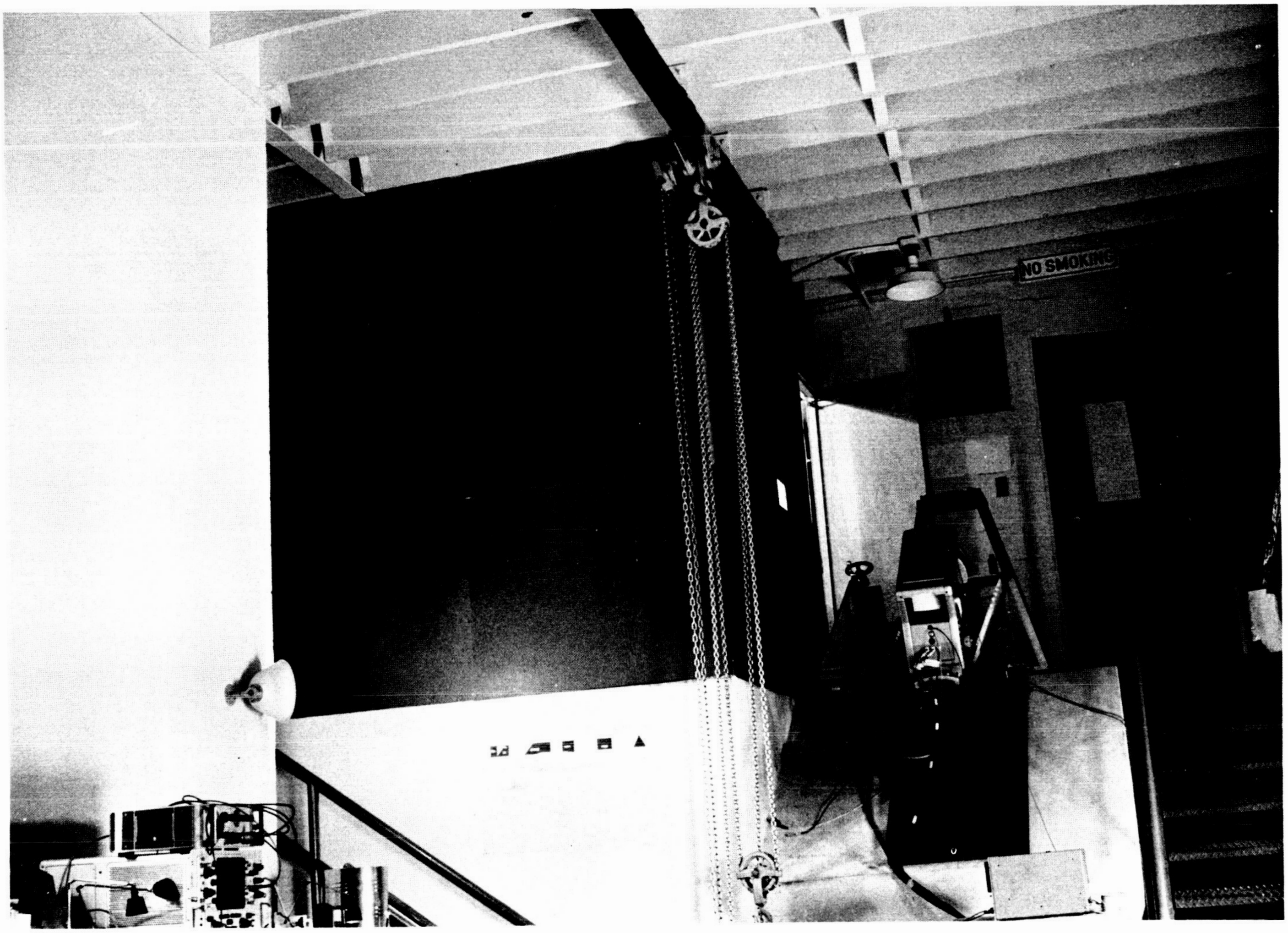

Fig. 1. The coudé platform of the 24-in. telescope, Table Mountain Observatory. The MK III Planetary Interferometer is enclosed in the room on the left side of the platform. The telescope beam enters through the hatch to the left of the closed door, is reflected through 90 deg by a mirror mounted on the framework (partially obscured by the TV camera) and enters the interferometer room through the small hole in the wall (shown illuminated).

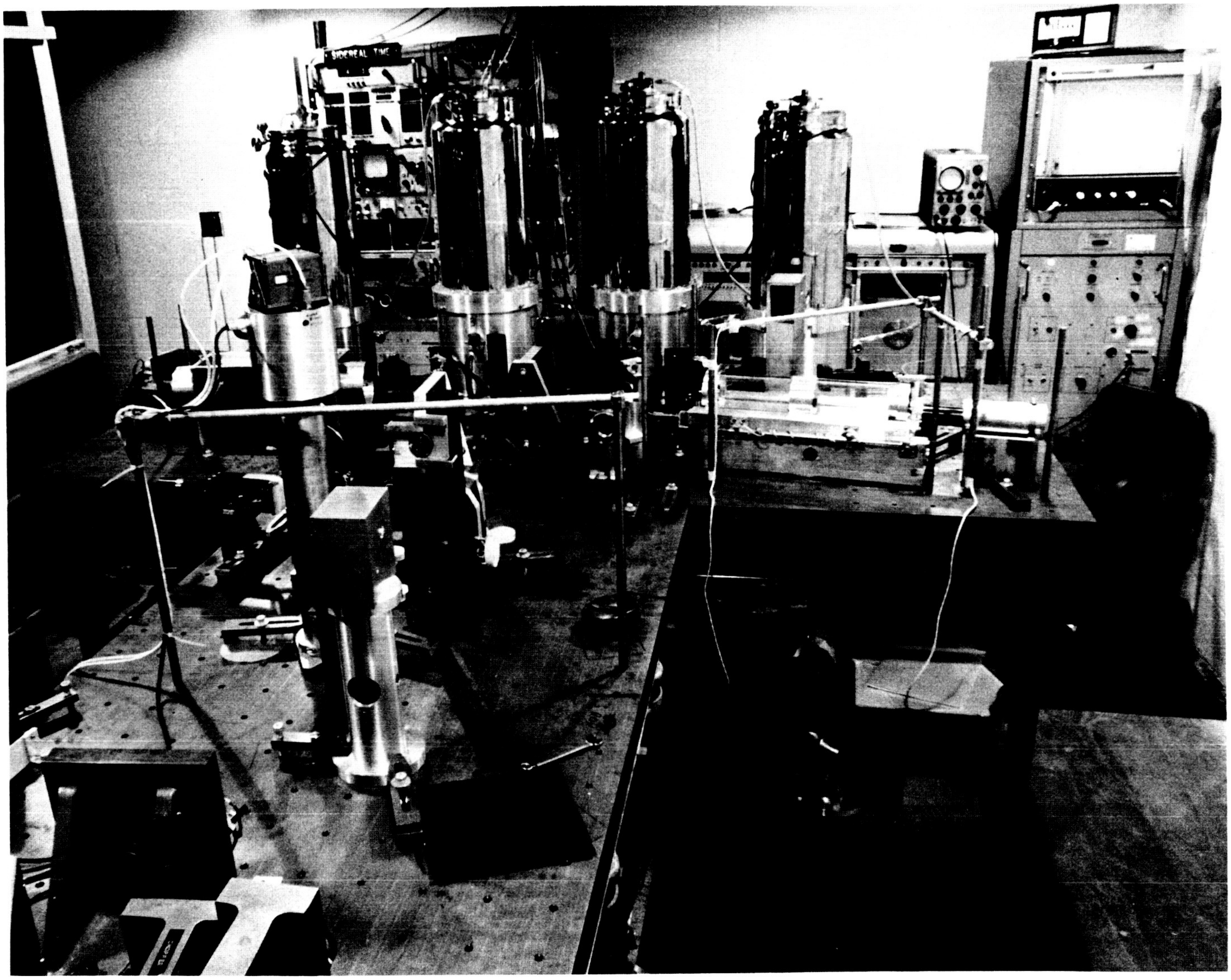

Fig. 2. General view of the interferometer. The table to the left carries the foreoptics, that completing the "T" carries the interferometer head itself. Behind can be seen the four detector dewars and the detector electronic system.

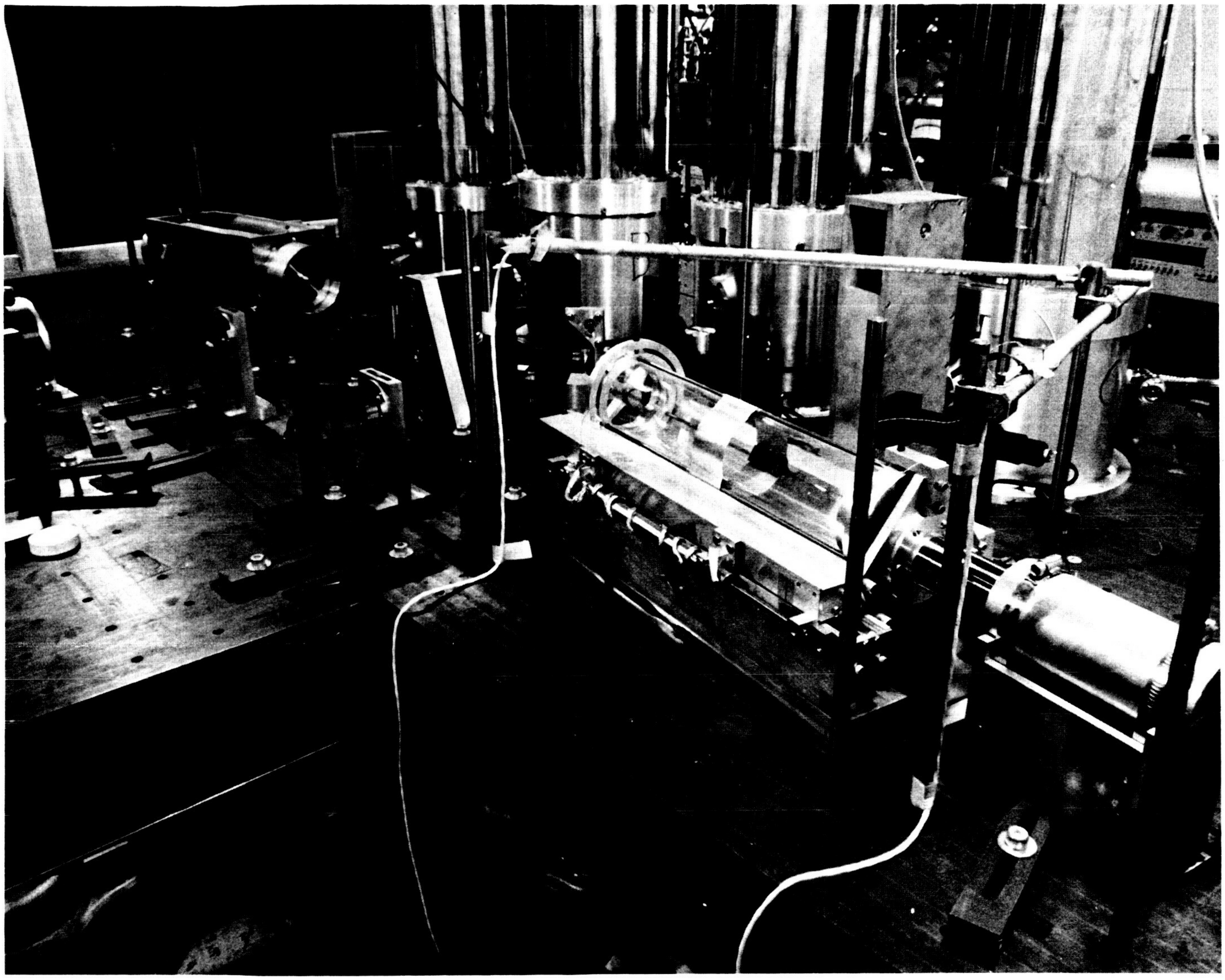

Fig. 3. A closeup view of the moving arm of the interferometer. The cat's-eye retro reflector rides on a kinematic carriage and is driven by the coil-and-magnet seen in the right foreground.

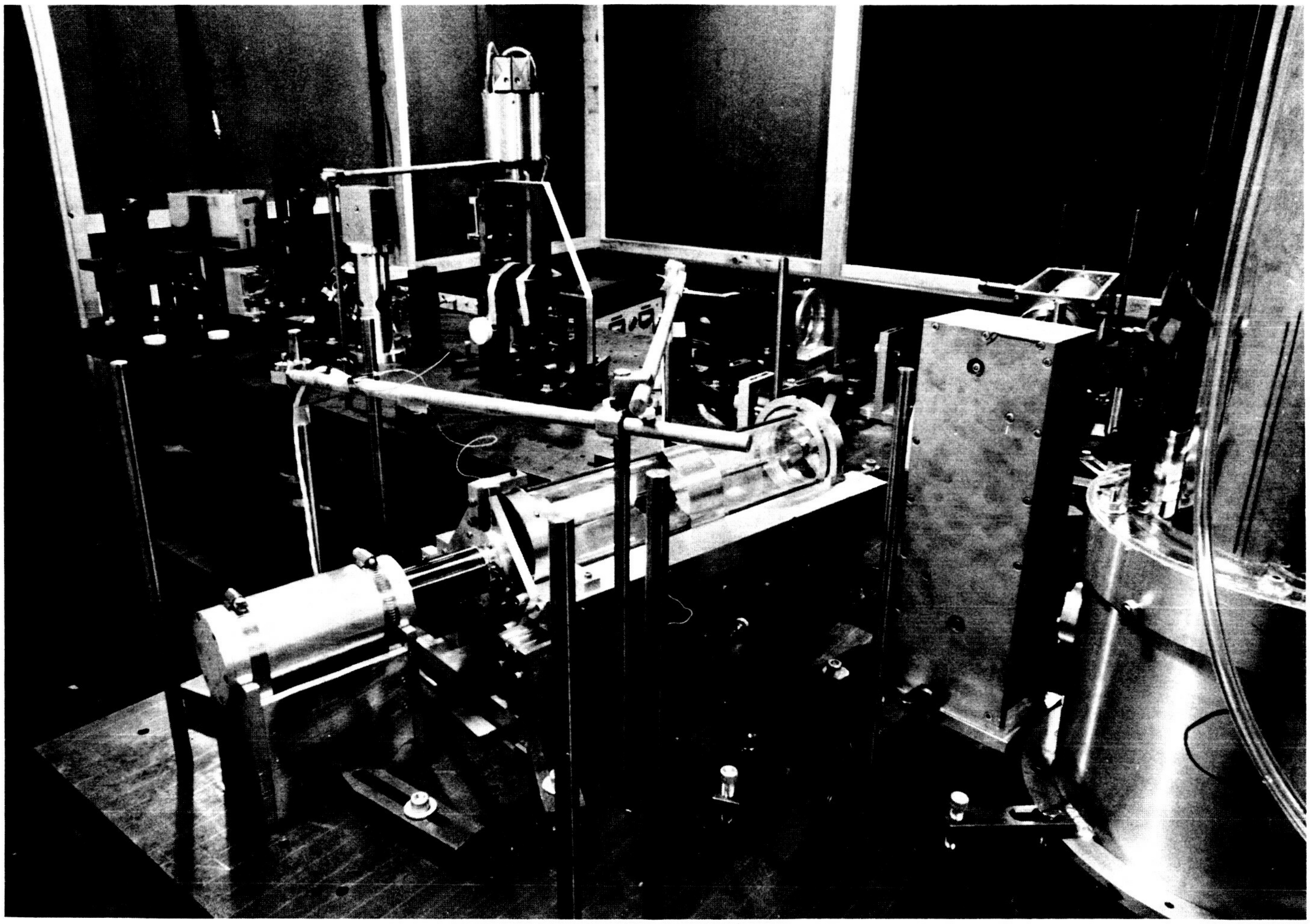

Fig. 4. General view of the foreoptics showing the biaxial image stabilizer, chopper, and collimators. The moving arm of the interferometer is again seen in the foreground.

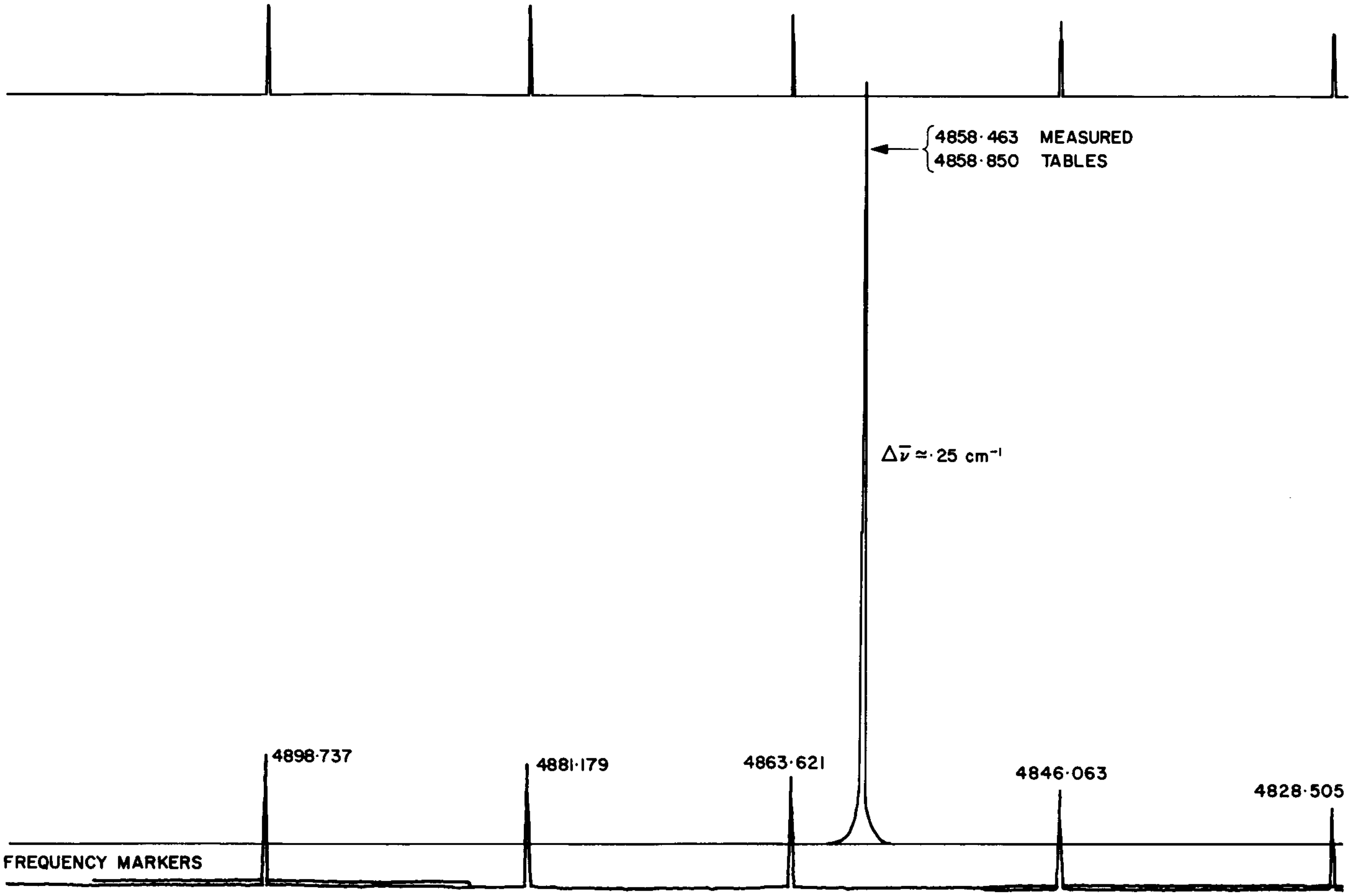

Fig. 5. Analog reduction of interferogram derived from the 2.06-μ helium line. The precision of the instrumentation can be infered from the fact that the line frequency could be determined to 0.4 cm^{-1} by direct measurement with a ruler from the internal frequency markers of the analog computer (accuracy ~1%).

GAS CHROMATOGRAPH-MASS SPECTROMETER STUDIES
NASA Work Unit 185-37-26-09-55
JPL 383-31501-1-3260
K. W. Charlton

OBJECTIVE

The long-range objective of this task is to develop a gas chromatograph/mass spectrometer (GC/MS) system capable of analyzing organic compounds on the surface of Mars. The immediate objective is the construction of a science breadboard model of this instrumentation. This will require a number of individual development efforts, including a pyrolyzer assembly, programmed-temperature gas chromatograph, carrier gas enrichment device, double-focusing double-radius mass spectrometer, chemical ion-pumping system, and a multipoint field ionization source. These components will be integrated into a gas chromatograph/mass spectrometer analysis system. An electronics console will provide necessary programming, control functions, and data readout. Figure 1 is a block diagram of the breadboard system.

PROGRESS

A pyrolyzer design has been completed in which the pyrolyzer housing serves both as the heating element and as the resistance element of a resistance-element bridge. With its associated electronic control system, this pyrolyzer can provide for controlled heating of soil samples from room temperature to 500°C in less than 15 s. Several types of experimental pyrolyzers have been fabricated and are currently undergoing evaluation. Design effort will continue in order to improve the method of soil sample introduction. Further tests will be conducted in order to learn more about the operating parameters of the pyrolyzer. Figure 2 shows the pyrolyzer fabricated for use with the GC/MS breadboard assembly.

The mechanical design of the gas chromatograph has been completed and assembly is now in progress. The electronic design is in progress. The gas chromatograph will be ready for initial testing in early September. Hydrogen carrier gas will be employed using conventional flow regulation. A stripper column with back-flushing provisions will allow for the rejection of unwanted components and will permit long-term operation of the system without column deterioration. The gas chromatograph column will employ programmed temperature control and will make use of the same temperature control electronics which were developed for the pyrolyzer. This will provide for any desired combination of isothermal operation and linear temperature programming of the column. A high-temperature thermistor thermal conductivity detector system with potentiometric recording will be employed for the conventional readout of the gas chromatograph peaks.

A carrier gas enrichment device will concentrate the sample before introduction into the mass spectrometer inlet system. Several types of enrichment methods are currently under consideration. The Lipsky type of Teflon tube separator has been evaluated. The separator failed at 340°C, and at the maximum safe temperature of 330°C enrichments of 57.2 and 108.6 were obtained for nitrogen and argon respectively, with sample recoveries of 70% for nitrogen and 55% for argon. Studies are now being conducted in the use of hydrogen carrier gas separators employing thin-wall palladium-silver tubing. Material is now being procured for the evaluation of the

Varian-type semipermeable membrane separator. In addition, tests are being conducted on a Ryhage separator to determine its potential as an enrichment device. An in-house study program has been initiated to consider each of these approaches from a theoretical standpoint and to determine which methods offer the greatest potential. Final selection of an approach and the development of an enrichment device for the breadboard will be deferred until the completion of this study program and the evaluation program.

The design of the double-radius mass spectrometer has been completed. Fabrication of components is in progress. Figure 3 shows a partial assembly of the analyzer. Initial testing will begin in early September. Figure 4 is a photograph of the double-radius magnetic sector housing.

There has been no additional progress in the development of the ion pumping system. The tantalum cylinders have been received, however, and will be coated with titanium in the near future. These units will be assembled with Pyrofuze, and initial tests on the pumping efficiency will be conducted. It is anticipated that an outside contract will be issued during FY 1968 for conducting additional development work on ion pumping systems.

Work continues on a research program by Dr. Stuart Hoenig at the University of Arizona on the development of a multipoint field ionization source for possible future application on the GC/MS breadboard system. The major emphasis has been upon the development of a source with a large and stable current output. Other objectives include the design of ion lenses and an investigation of field ionization techniques for the analysis of planetary atmospheres. Dr. Hoenig has developed a platinum multipoint source which has given good performance with stable currents. A redesign of the ionization source for the production of low energy ions (30 V) has been completed and evaluation of the new design is now in progress.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

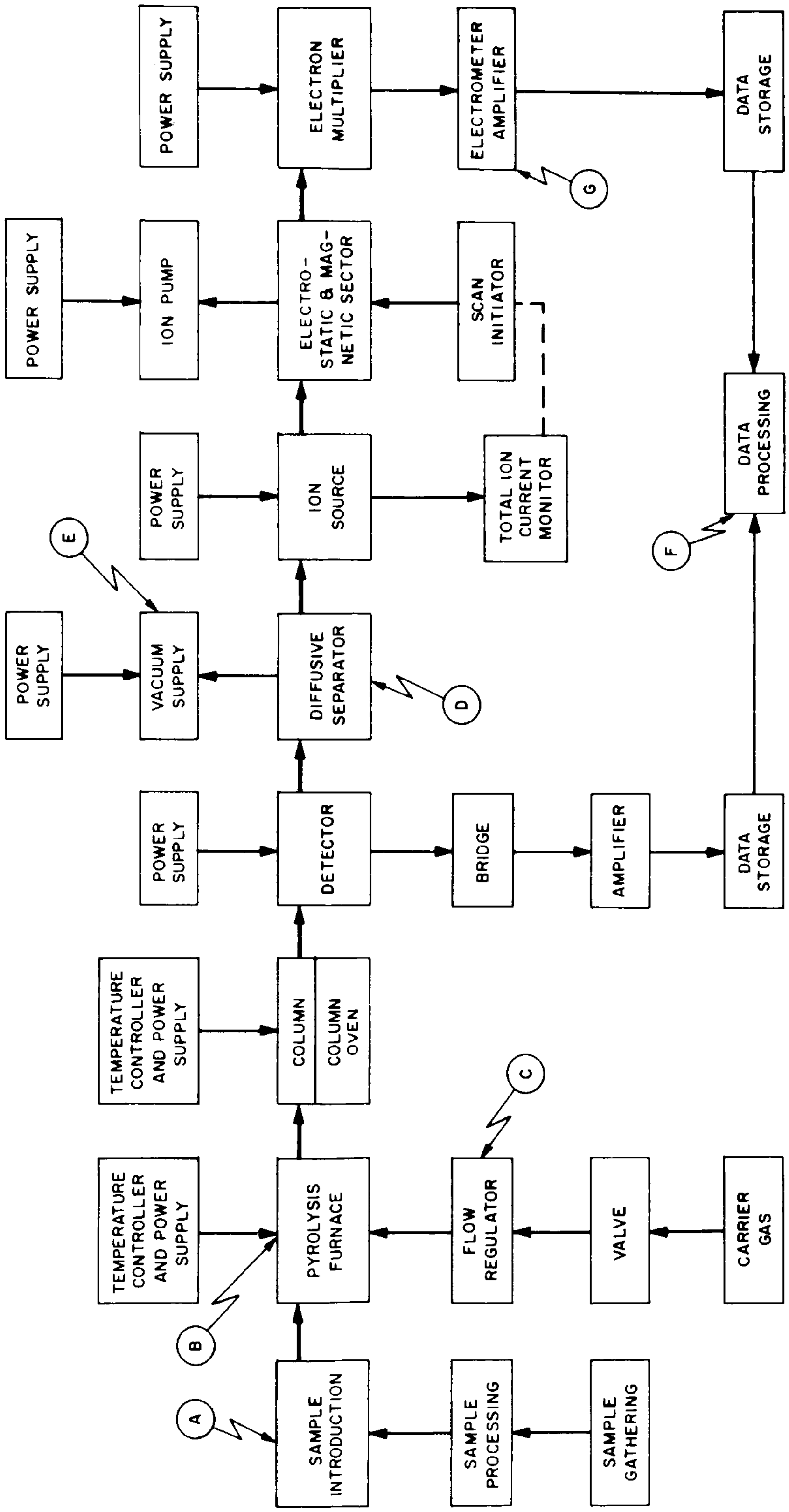

Fig. 1. Simplified block diagram of GC/MS organic analysis

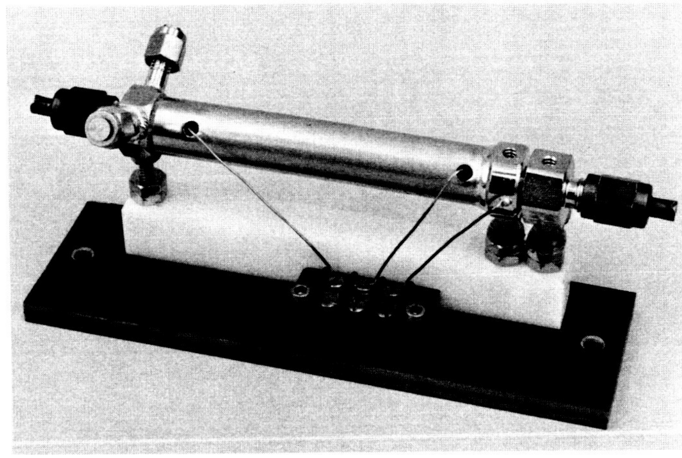

Fig. 2. Pyrolzer

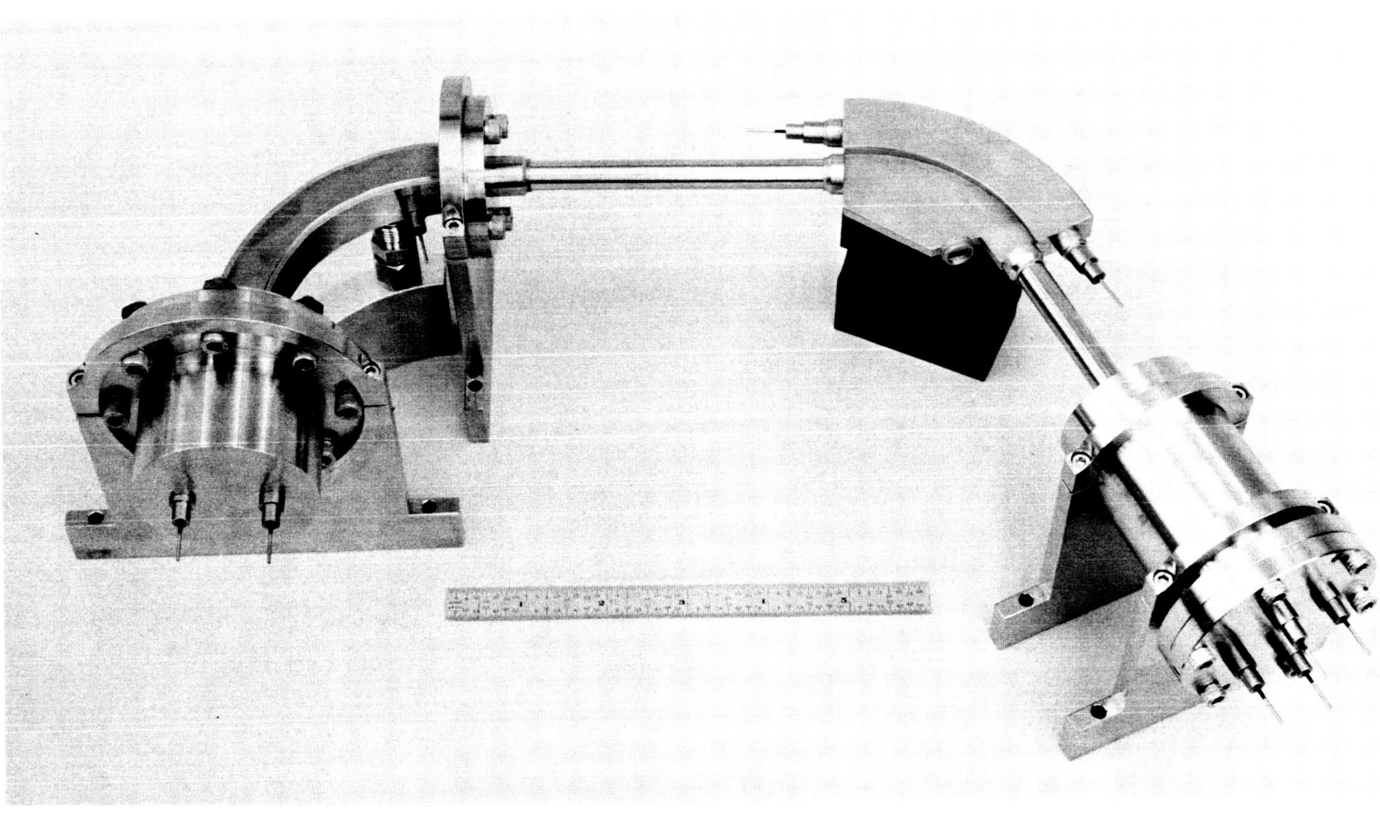

Fig. 3. Double-focus dual-radius magnetic sector mass spectrometer

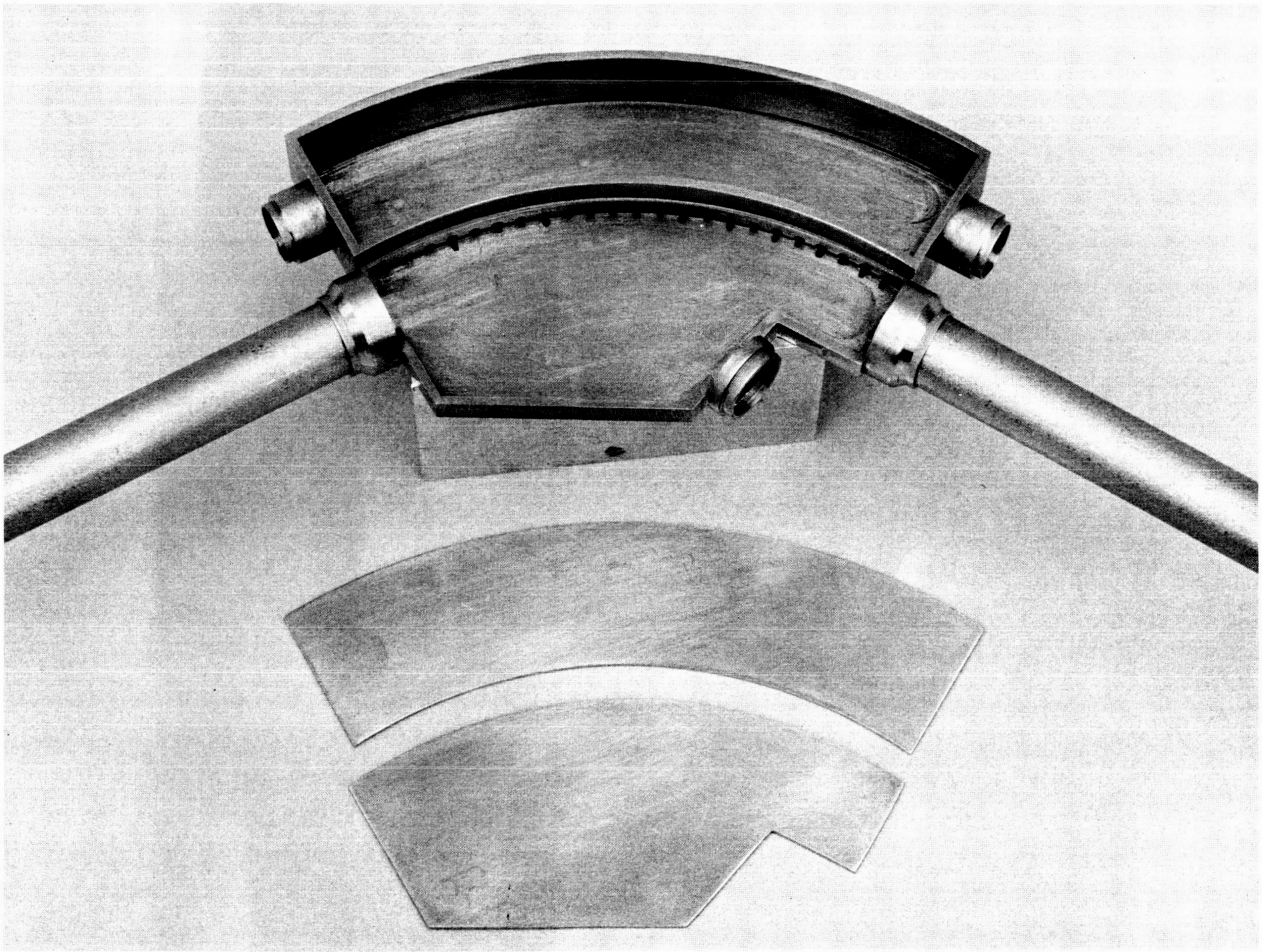

Fig. 4. Double-radius magnetic sector

IR SPECTROSCOPY OF SYNTHETIC ATMOSPHERES

NASA Work Unit 185-37-26-16-55
JPL 383-32801-2-3250

J. S. Margolis

OBJECTIVE

The objective of this work unit is to provide data for understanding the spectra of planetary atmospheres. This is accomplished by taking spectra of gases in long-path-length cells under conditions which are thought to simulate those on the planets. The spectral region generally used is the near infrared.

PROGRESS

Optics

The construction of a new 2-m multipass cell has been completed. A few minor discrepancies in the fabrication are being corrected. The cell will operate over a temperature range from room temperature to dry ice temperatures. The path length obtainable is 160 m (80 passes), and the cell will sustain internal pressures up to 10 atm. The feasibility of reworking the 6-m white cell in order to remove mechanical vibration was investigated and proved.

Electronics and Data Handling

Data obtained from the spectrometers are being written on magnetic tape and processed on the PDP-4 computer which converts a linear wavelength scale into a linear frequency scale and plots the result on a strip chart.

The image intensifier tube has been prepared for operation. This includes the preparation of high-voltage power supplies, a cooling mechanism for the S-1 photocathode and related optical parts for photographing the enhanced image. The image intensifier tube will be used in high-resolution studies with the 5-m spectrograph and for spectroscopic observations of the planets at Kitt Peak Observatory.

1.8-m Spectrometer

Extensive high-resolution spectra of CO_2 have been taken for use in the analysis of the Martian spectra obtained by P. and J. Connes. These have been obtained with path lengths of several hundred meters, requiring the use of the 6-m white cell.

Spectra of COS, H_2S, SO_2, and CS_2 have also been obtained under varying conditions. These were used to provide rate constant data for a chemical kinetic calculation of the temperature of the surface on Venus.

Solar spectra have been taken with the 5-m spectrograph with a quality comparable to that available in the standard solar atlas. These were obtained

as part of a sideline, noninterfering experiment to determine the usefulness of spectroscopy to the study of atmospheric constituents of smog. We await a sufficiently smoggy day to make comparison spectra.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

Meetings and Symposia Papers

1. Beckman, J. E., "The Cloud Top Model for the Upper Atmosphere of Jupiter," to be presented at the Summer Meeting of the Astronomical Society of the Pacific, 1967.

2. Fox, K., and Beckman, J. E., "The IR Absorption Spectrum of CH_4 at 7500 cm^{-1}," to be presented at the Molecular Spectroscopy Symposium at the University of Ohio, 1967.

Open Literature

1. Beckman, J. E., "Measurement of Planetary Gaseous Abundances Using an Image Intensifier and Solar Spectrograph," J. Planetary and Space Science (in press).

2. Beckman, J. E., "The Pressure at the Cloud Top and Abundance of Hydrogen in the Atmosphere of Jupiter," Astrophys. J., August 1967.

3. Connes, P., Connes, J., and Beckman, J. E., "The Spectrum of Jupiter at 0.6 and 1.25 Microns" (in review by the Connes).

JPL SPS Contribution

1. Beckman, J. E., "The Pressure at the Cloud Top and the Abundance of Hydrogen in the Atmosphere of Jupiter," SPS 37-45, Vol. IV, in press.

ASTRONOMY (185-41)

SPECTRAL REFLECTANCE OF PLANETARY SURFACES

NASA Work Unit 185-41-08-01-55
JPL 383-10401-2-3250

J. B. Adams

OBJECTIVE

The objective of the program is to develop a basis for geologic interpretation of spectral reflectance measurements of planetary surfaces.

PROGRESS

A laboratory study of the spectral reflectance of common mineral and rock powders in the range of 0.4 to 2.5 μ has shown that the most important variables are mineral composition and particle size. Other variables, particle packing and particle shape, affect spectral reflectance properties to a lesser extent except in special situations that are unlikely in nature. Given some idea of particle-size distribution, it is possible to determine gross rock composition by a combination of several reflectance properties, including the ratio of light reflected at 0.7 to that at 0.4 μ, the change in this ratio with variations in normal albedo, the maximum albedo of the rock in powdered form, and the presence or absence of broad absorption bands. A paper discussing these results has been accepted for publication in the Journal of Geophysical Research under the title "Spectral Reflectance 0.4 μ to 2.0 μ of Silicate Rock Powders."

The laboratory results have been used as a basis for interpretation of spectral reflectance measurements of the moon. Evidence has been found that many of the albedo differences on the moon can be explained by areal differences in mean particle size. In addition, the spectral reflectance data for the moon are compatible with basic rock such as basalt, but not with acidic rock such as rhyolite, pumice, etc. Lunar reddening with increasing phase angle, and the brighter-the-redder function, are explained by similar results with basalt powders in the laboratory. The interpretation of the lunar data is discussed in a paper to be published in the Journal of Geophysical Research entitled "Lunar Surface Composition and Particle Size; Implications from Laboratory and Lunar Spectral Reflectance Data."

Work is continuing in the laboratory using absorption bands in the near IR to identify minerals and rocks in particulate form. This approach appears promising and a preliminary report is in progress.

PLANNED ACTIVITIES

Further work in this area will be supported under "Planetology," NASA Work Unit 185-42-52-01-55, JPL 383-20101-2-3250. In addition to further work on absorption bands in silicate powders, attention is being given to interpretation of Mars spectral reflectance data.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

Open Literature

1. Adams, John B., "Lunar Surface Composition and Particle Size; Implications from Laboratory and Lunar Spectral Reflectance Data," J. Geophys. Res., in press, 1967.

2. Adams, John B., and Filice, Alan L., "Spectral Reflectance 0.4 μ to 2.0 μ of Silicate Rock Powders," J. Geophys. Res., in press, 1967.

OPTICAL ASTRONOMY
NASA Work Unit 185-41-21-01-55
JPL 383-10201-2-3250
Robert H. Norton

OBJECTIVE

All available techniques of ground-based optical astronomy will be used to study the bodies of the solar system in order to furnish the best possible description of the surfaces and atmospheres of those bodies to engineers for spacecraft design and to engineers and scientists for experiment design.

PROGRESS

Equipment

The 24-in. telescope at Table Mountain was brought to full operation in April with the installation of the lunar and planetary declination drive. The Mark III Connes-Type Fourier spectrometer under development by R. Beer is now installed on the coudé platform and preliminary observations have commenced. The 1-m Ebert scanning monochrometer has been adapted for use at the 24-in. Cassegrain focus by J. Gunn, and the instrument will be fully operative as soon as the power supplies for the pulse-counting system have been received. The design of the sophisticated new planetary coudé camera is virtually complete and will be in operation by the end of the summer. The camera for the 24-in. Cassegrain focus, designed by J. Gunn, is now in operation. An image orthicon system was modified by E. Miner and D. Willingham for the 24-in. coudé focus and was installed in May; preliminary shakedown of the system is now under way.

It had originally been hoped that a contract for the coudé spectrograph, approval for which had been obtained from NASA Headquarters, could be signed before the end of FY 1967. This was found not to be possible because of much higher bids than anticipated, requiring a revised RFP. A new RFP will be issued against FY 1968 funds, if they can be made available.

Internal Observing Program

An in-depth observational patrol of Mars, including photography in six bands, micrometer measurements, and polarimetry, is being conducted by C. Capen. Most of this observing has been accomplished with the Table Mountain telescopes, but it has also been supplemented with observations made at the 82-in. Struve Reflector at McDonald Observatory. The photographic patrol of Venus is being continued by C. Capen and J. Young.

As chairman of the Astronomy Working Group for the Surveyor project, R. Norton has cognizance over an experiment to photograph the solar corona with the Surveyor television camera.

A large number of research programs, not all under this work unit, are planned for the 24-in. facility. J. Gunn will use the scanning monochrometer in a search for

auroral lines on Venus and will also use the data to obtain the upper structure of that atmosphere. E. Miner and D. Willingham will view different surface areas on Mars at various phase angles with the image orthicon to derive detailed photometric functions. R. Beer, R. Norton, C. B. Farmer, and L. Kaplan will study the infrared (1 to 4 μ) spectra of the planets with the MK III interferometer.

External Observing Program

R. Younkin has continued his spectrophotometric observations of Mars at the 60-in. reflector at Mount Wilson. These observations are aimed at the determination of the photometric functions of Martian light and dark regions.

R. Schorn and L. Gray, in collaboration with R. Moore (RAND Corp.) and E. Barker (University of Texas), have been conducting an extensive observing program at McDonald Observatory. Preliminary examination of the spectra suggests that there have been no dramatic changes in the strengths of the CO_2 lines on Mars. The search for water vapor on Mars has produced negative results, with an upper limit of 10 μ precipitable water. Observations of the 1.0 and 1.2 μ CO_2 bands of Venus and Mars have been conducted with an infrared image tube in collaboration with J. Beckman of the Atmospheric Physics Group, and preliminary success in this field is very exciting.

PUBLICATIONS DURING REPORT PERIOD

Meetings and Symposia Papers

1. Smith, H. J., Gray, L. D., Barker, E. S., and Schorn, R. A., "Use of an Infrared Image Tube for High-Dispersion Planetary Spectroscopy," American Astronomical Society, June 12-15, 1967.

2. Gray, L. D., Moore, R. C., and Schorn, R. A., "Carbon Dioxide Bands in the Atmosphere of Venus," American Astronomical Society, June 12-15, 1967.

3. Spinrad, H., and Miner, E. D., "Results of Very High-Dispersion Spectroscopy of Comet Ikeya-Seki," Astronomical Society of the Pacific, June 29-30, 1967.

Open Literature

1. McClatchey, R. A., and Norton, R. H., "Atmospheric Sensing With CO_2 Lasers," Proceedings of the Remote Electromagnetic Sensing Symposium, Brooklyn Polytechnic Press, January 1967.

2. Schorn, R. A., Spinrad, H., et al., "High-Dispersion Spectroscopic Observations of Mars. II. The Water Vapor Variations," Astrophys. J., 147, 743 (1967).

3. Capen, C., "Observing Mars: The 1966-67 Apparition," Sky and Telescope, 33, 208 (1967).

4. Schorn, R. A., and Gray, L. D., "The Martian Surface Pressure," Astrophys. J., 148, 663 (1967).

JPL SPS Contributions

1. Norton, R. H., "Coudé Facility for the Table Mountain 24-Inch Telescope," SPS 37-43, Vol. IV, pp 293-294, February 1967.

2. Capen, C. F., "Mars Patrol 1964-65," SPS 37-43, Vol. IV, February 1967.

JPL Technical Reports

1. Capen, C. F., The Mars 1964-65 Apparition, TR 32-990, December 15, 1966.

ANTICIPATED PUBLICATIONS

Open Literature

1. Capen, C., and Young, J. W., "Observations of the November 1966 Leonid Meteor Storm," Icarus, accepted for publication.

2. Schorn, R. A., Encyclopedia of Earth Sciences, Chapters on Venus and Mars, Reinhold Press, to appear in 1967.

3. Gray, L. D., and Schorn, R. A., "The 1-Micron Carbon Dioxide Bands on Venus. I. Analysis Using a Simple Non-Scattering Atmospheric Model," Astrophys. J., accepted for publication.

4. Schorn, R. A., "Water Vapor in the Martian Atmosphere," Science, (invited paper to be submitted for publication).

5. Gunn, J. E., "Photon Noise in Fourier Spectroscopy," Appl. Opt., submitted for publication.

6. Gunn, J. E., "The Grille Spectrograph in Astronomical Spectroscopy," Appl. Opt., submitted for publication.

7. Gunn, J. E., "Solar Wind Bombardment of Planetary Atmospheres," Astrophys. J., to be submitted for publication.

8. Younkin, R. L., and Münch, G., "Spectrophotometry of Uranus from 3300 to 11000 A," in final stages of rewrite.

9. Younkin, R. L., "The Absolute Energy Distribution and Color of Syrtis Major and Aeria-Arabia," Astrophys. J., to be submitted for publication.

RADIO ASTRONOMY

NASA Work Unit 185-41-21-02-55
JPL 383-10301-2-3250
D. E. Jones

OBJECTIVE

The objective of the Radio Astronomy Program is to increase our understanding of the moon and nearer planets by means of (1) ground-based passive radio astronomy at centimeter and millimeter wavelengths and (2) ground-based radar observations.

PROGRESS

Venus Microwave Observations

Observations of Venus at a number of frequencies between 20 and 24 GHz have been made during the inferior conjunctions of 1964 and 1966 and again near the superior conjunction of 1966. The 1964 observations extended only over a 17-day period shortly after inferior conjunction, whereas the 1966 observations extended over a 60-day period beginning shortly after inferior conjunction, and over a 40-day period just prior to superior conjunction. All of these data suggest that an emission feature may exist near 22.2 GHz. The phase angle dependence of the brightness temperature at 20 and 21 GHz appears to be compatible with an extrapolation of the data at 3 and 10 GHz reported by others, whereas at or near 22.2 GHz the phase effect is much more pronounced. Other aspects of the time variability observed in the data are being studied. The data from channel 2 (21 to 23 GHz) of the Mariner II microwave radiometer are also being reanalyzed and compared to the ground-based data.

Preparations are under way for an extensive observation program of Venus at 25 frequencies over the 20 to 24 GHz interval utilizing the 30-ft antenna at Goldstone. These observations should continue over at least one complete orbital period.

Venus CW Radar

The analysis of the 1965-1966 Venus radar data is essentially complete. The rotation has been determined from the motion of two features on the CW spectra. One of the features is believed to have been observed during three successive conjunctions, 1962, 1964, and 1966. The other was observed in 1964 and 1966 only. The sidereal rotation periods obtained are -243.24 ± 0.1 and -243.23 ± 0.15 days, respectively. The RA and DEC of the direction of the northern pole are $79^\circ.6$, $+73^\circ.5$ and $72^\circ.5$, $+74^\circ.2$, respectively. Note that the rotation periods overlap the synodic synchronism case of -243.16 days. The positions of the above features, along with several others, have also been located in a planetocentric coordinate system. A paper describing these results is now in preparation.

Table Mountain Facility

The 18-ft Cassegrain antenna has been received, assembled, and installed on its pedestal at Table Mountain. Preliminary measurements have been made of the antenna pattern and gain, indicating that the characteristics of the dish are close to the required specifications. Intensive evaluation of the dish will continue through June, with calibration measurements related to pointing, etc., being started the last of June or first of July. Lunar, planetary, and radio source observations will start in late July at 8 mm.

There has been a recent earth movement that will require relocation of the boresight facility that is presently located on Wrightwood Mountain. Plans are presently being formulated to move this facility within the next three months.

PUBLICATIONS DURING REPORT PERIOD

Open Literature

1. Gary, B., "Results of a Radiometric Moon-Mapping Investigation at 3-Millimeters Wavelength," Astrophys. J., 147, 245, 1967.

JPL SPS Contribution

1. Jones, D. E., Meredith, B. L., and Wrathall, D., "Observations of the Radio Emission from Venus at 1.5-cm Wavelength," SPS 37-43, Vol. IV, February 1967.

ANTICIPATED PUBLICATIONS

Open Literature

1. Carpenter, R. L. and Goldstein, R., "Radar Observations of Venus," Astron. J., to be submitted within next two months.

2. Gary, B., "Mercury's Microwave Phase Effect," submitted to the Astrophys. J., June 1967.

PLANETOLOGY (185-42)

PLANETOLOGY
NASA Work Unit 185-42-20-01-55
JPL 383-20101-2-3250
D. B. Nash
A. A. Loomis

OBJECTIVE

The objectives of the Planetology Task are to pursue experimental and theoretical research projects directed toward an understanding of the origin and evolution of the bodies, surfaces, and atmospheres of the moon and planets.

Specific objectives for FY 1967 have been: (1) continuation of studies of proton-induced luminescence and darkening of silicates with applications to solar wind bombardment of the moon, (2) completion of lunar terrain study and preparation of manuscript for publication, and (3) calculations of volcanic and atmospheric chemical equilibria with application to Mars surface and atmosphere.

PROGRESS

Proton-Irradiation Studies - D. B. Nash

The results of the experiments on proton-induced darkening of silicate powders have been published (J. Geophys. Res., Vol. 72, No. 12). Articles by Wehner and Hapke, essentially confirming these results, appeared in the same journal issue. Darkening of silicate rock powders (Fig. 1) by bombardment with 2 to 16 keV protons has been found to be slight unless proton flux or total proton incident-power density is sufficient to produce sample surface temperature in excess of about 150°C. Darkening then increases with incident power density for a given proton dose, i.e., the darkening is rate- and temperature-dependent as well as dose-dependent (Fig. 2). The darkening is due to contamination (Fig. 3) by carbon from irradiation decomposition of hydrocarbon vacuum contaminants and/or by metal atoms deposited on the sample surface from sputtering of ion source components. The photometric properties of the contamination-darkened samples are similar to those reported for samples darkened with hydrogen ions by Hapke, Wehner, et al. (Fig. 4). This result suggests that contamination darkening may have caused the photometric modifications that they report. A review and comparison of experimental apparatus and procedures is presented (Fig. 5). The experimental conditions under which silicate powders darken by proton or hydrogen-ion bombardment are shown to be unrealistic for simulation of solar wind darkening of the surface of the moon. It is suggested, however, that deposition of solar carbon on the moon may occur in sufficient amounts to produce darkening.

Lunar Terrain Study - A. Loomis and A. Filice

The colored lunar terrain map which updates that of the 1964 Lunar Terrain Study (JPL TM 33-172) is complete. The map was incorporated in the Surveyor Project Lunar Scientific Model (Project Document No. 54; Rev. 1; December 15, 1966). A rough draft of the manuscript summarizing the lunar terrain is completed and is being circulated for review.

Volcanic and Atmospheric Chemical Equilibria - A. Loomis

This study is a theroretical consideration of (1) the mineral-gas equilibrium relations of silicate rocks and their surrounding atmosphere and (2) the diffusive properties of radiogenic gases within rocks.

An IBM 7094 program to determine the equilibrium compositions of various multicomponent solid-liquid-gas systems has been acquired from NOTS. Much difficulty has been encountered in running the program in the JPL computer center. The program has required several procedural modifications which are not yet complete. The calculations consist of a sequence of iterations directed toward minimizing the free energy of a system at a given P, T point once the masses and identities of the original components are given. The results will be applied to the atmospheres and surfaces of Venus and Mars. A possible application, for example, is determination of the products of a C, H, O, N mixture which could be in equilibrium with various amounts of atmospheric halides or reduced hydrocarbon compounds.

PUBLICATIONS DURING REPORT PERIOD

Meetings and Symposia Papers

1. Loomis, A. A., "A Lunar and Planetary Petrography Experiment," presented at the American Astronautical Society Meeting in Boston, May 25-27, 1967.

2. Loomis, A. A., "Relation of Gravity to Geology, Placerville to Lake Tahoe, Sierra Nevada," presented at the Geological Society of America Meeting, Cordilleran Section, University of California at Santa Barbara, March 23-25, 1967.

Open Literature

1. Nash, D. B., "Proton-Irradiation Darkening of Rock Powders and Solar-Wind Darkening of the Moon," J. Geophys. Res., Vol. 72, 1967.

2. Loomis, A. A., Bourke, R. D., and DeBra, D. B., "A Method of Obtaining the Radius of Mars," J. Geophys. Res., Vol. 72, pp. 1265-1268, February 15, 1967.

JPL SPS Contribution

1. Filice, A. L., "Use of the Visible and Near IR Spectrum in Analysis of the Lunar Surface," SPS 37-45, June 1967.

ANTICIPATED PUBLICATIONS

JPL Technical Report

1. Loomis, A. A., and Filice, A., The Lunar Terrain, TM 32-1050, in preparation.

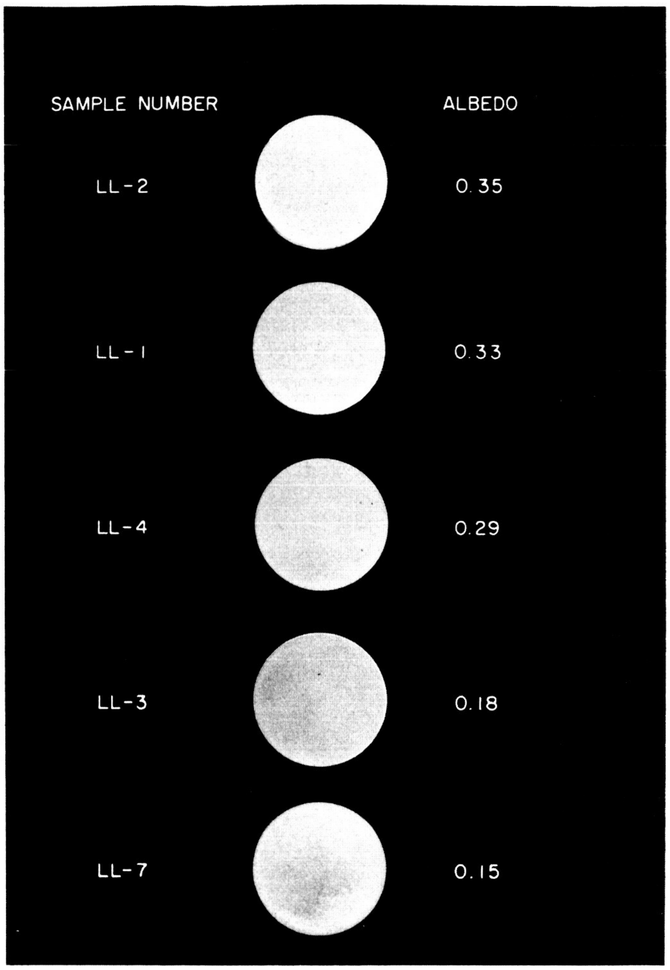

Fig. 1. Proton-irradiated basalt samples

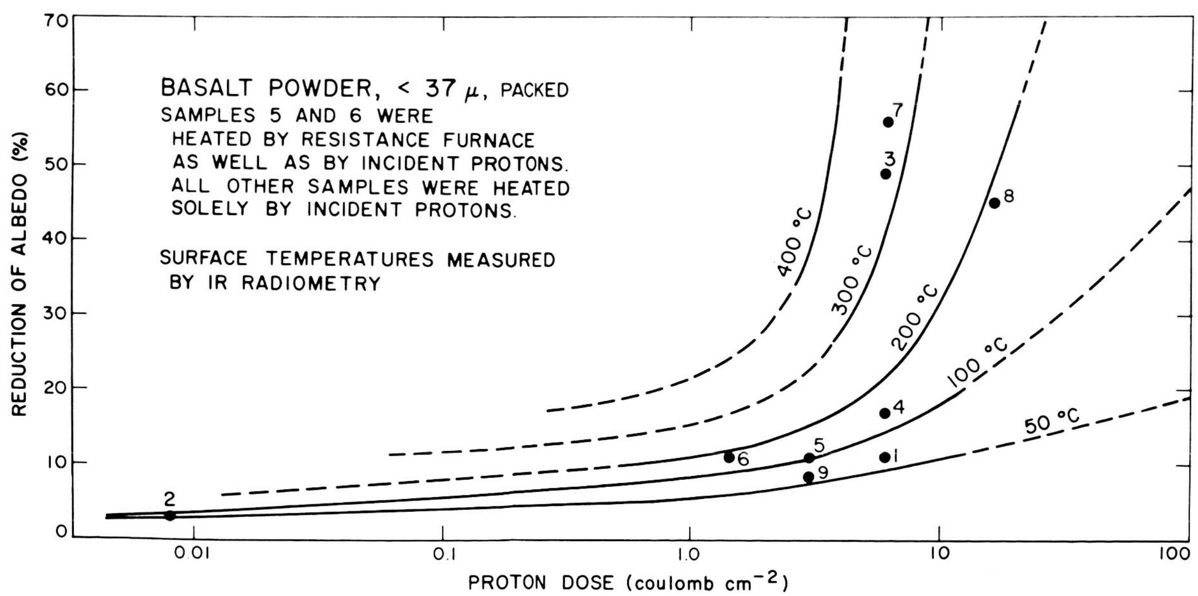

Fig. 2. Temperature dependency of darkening rate

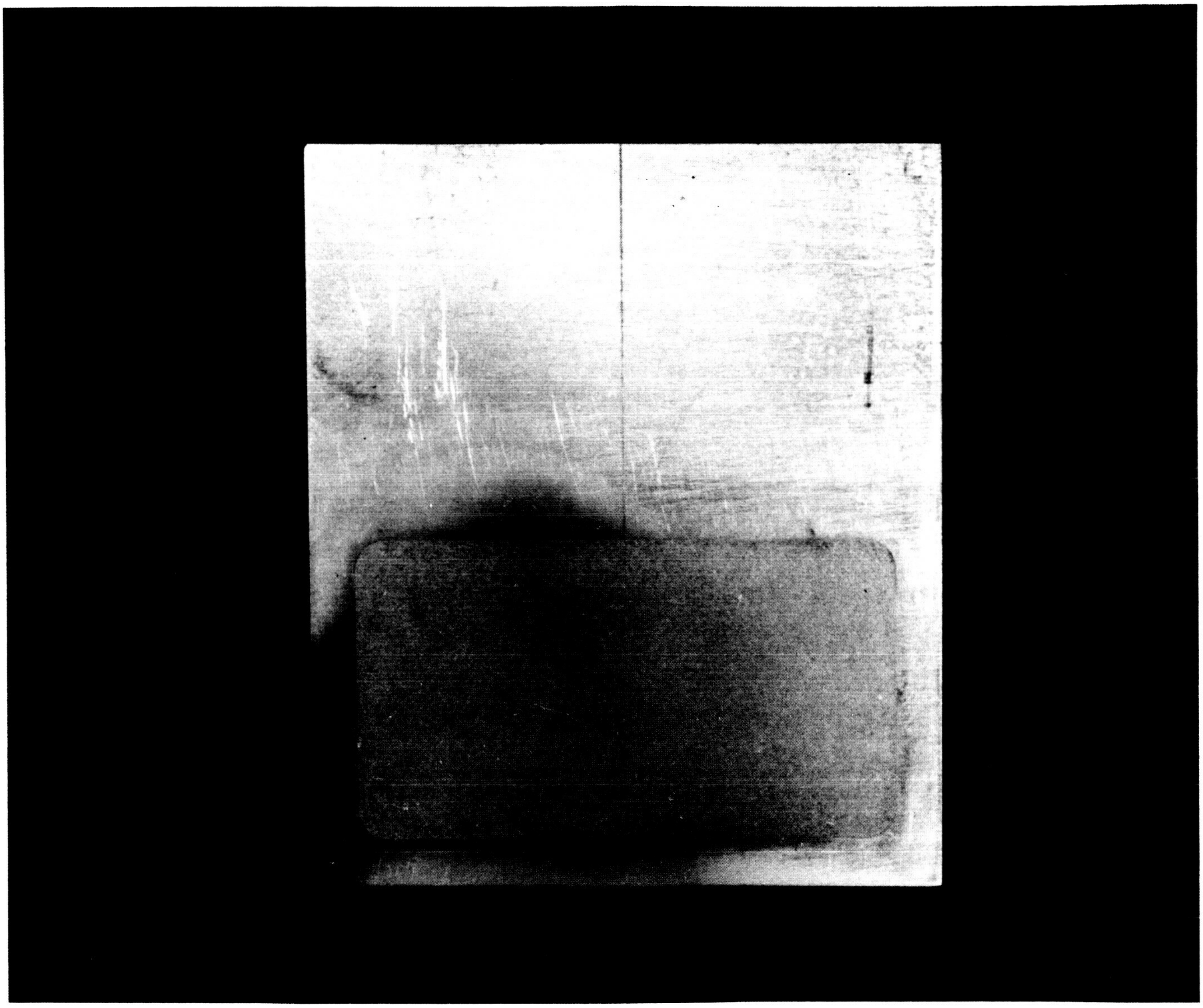

Fig. 3. Contamination darkening of sample and sample cup

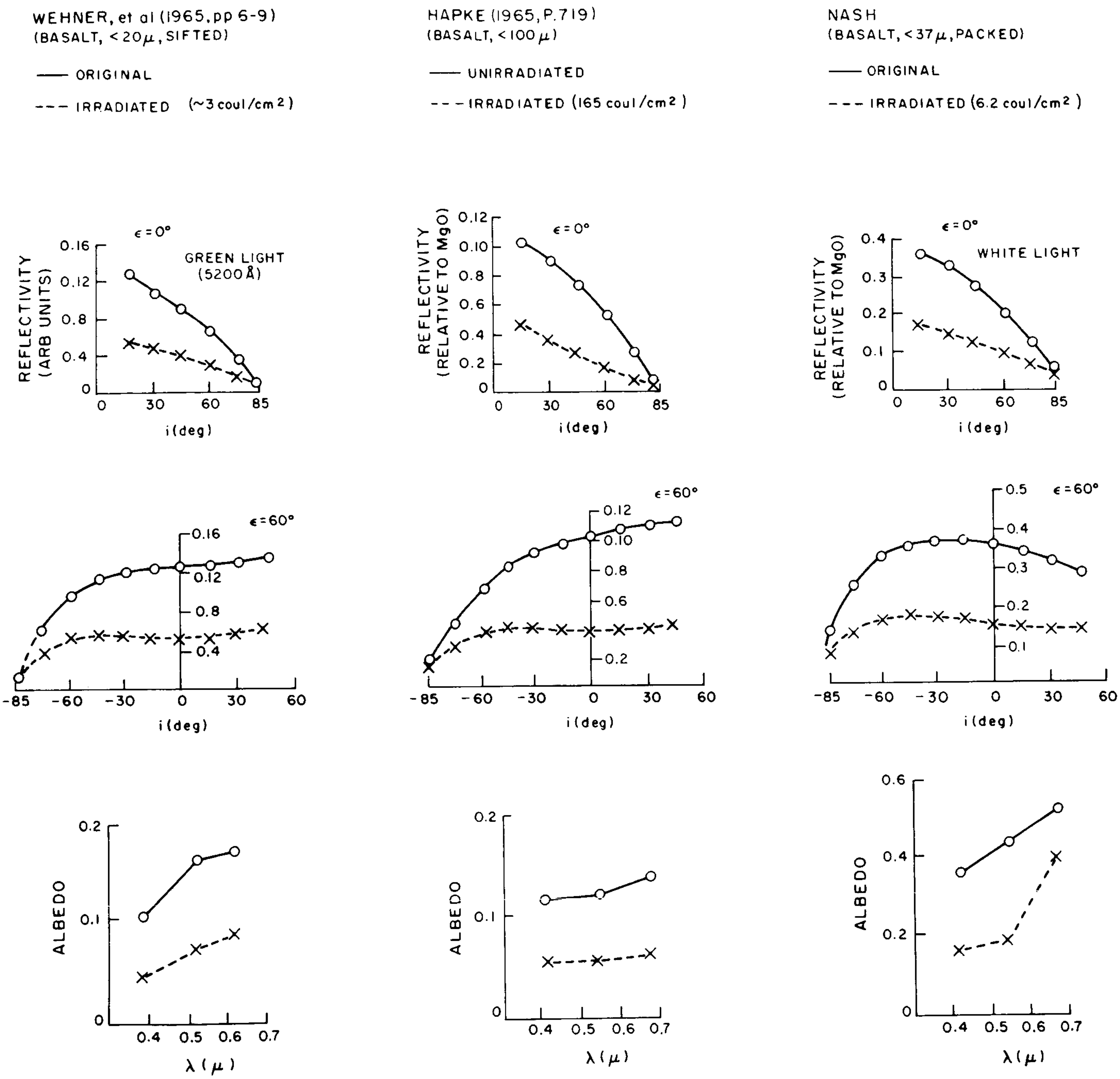

Fig. 4. Comparative photometric data for bombardment darkening by different investigators

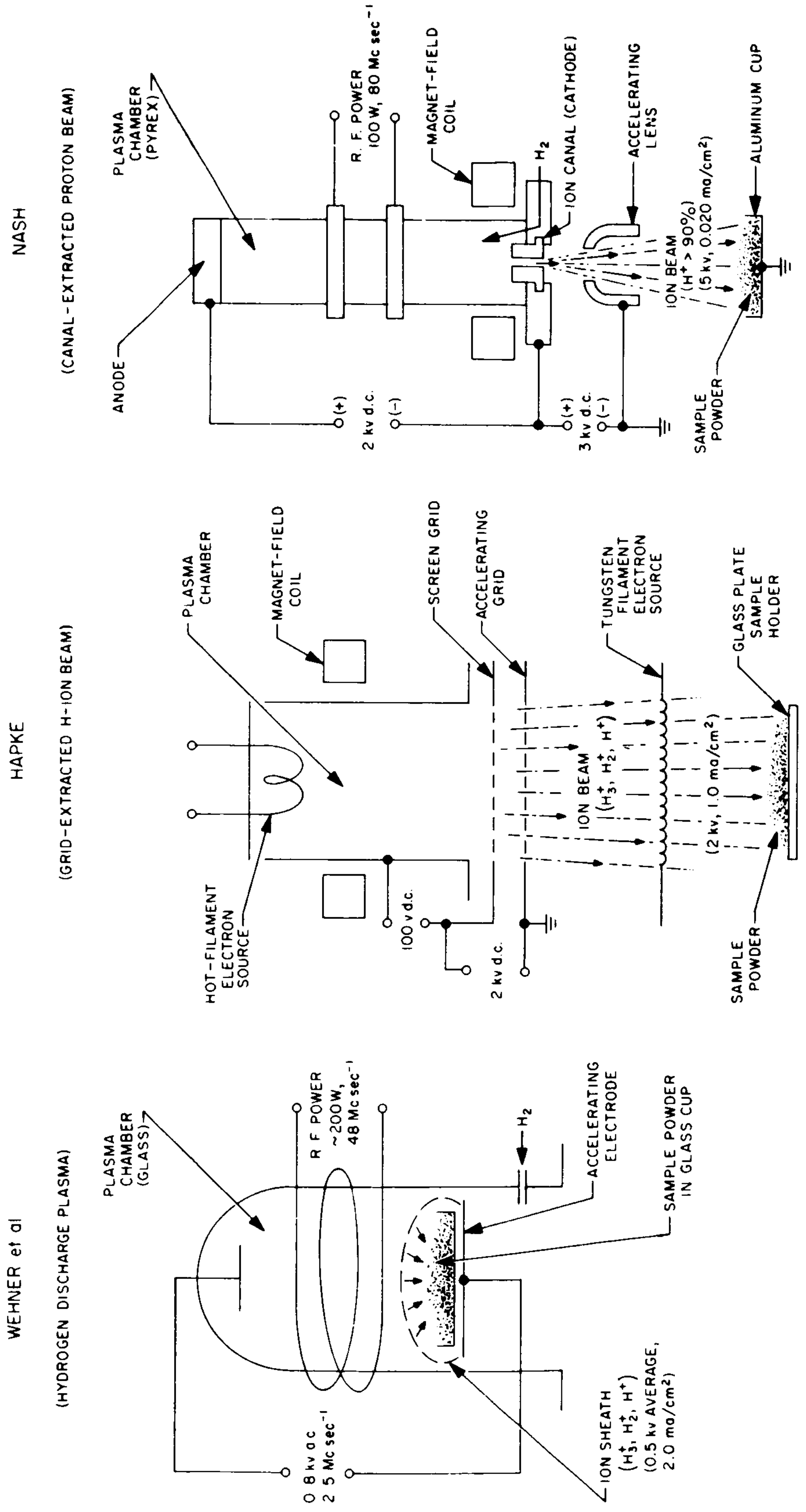

Fig. 5. Schematic of irradiation systems used by different investigators

PETROGRAPHIC STUDIES
NASA Work Unit 185-42-20-02-55
JPL 383-20201-2-3250

A. A. Loomis

OBJECTIVE

The long-range program objective is the development of a remotely operating petrographic microscope for use in exploration of the moon and planets.

The objective for FY 1967 has been the design, fabrication, and environmental testing of an engineering prototype model of the instrument. This effort completes the task.

PROGRESS

This work unit is now complete and has resulted in production of an engineering prototype instrument believed adequate to serve as the basis for a flight experiment proposal. Since this is the last semiannual report on this task, the instrument will be described in some detail.

The prototype model was completed in April 1967. The mechanism of the instrument was designed by Mr. Allen G. Ford of the JPL Design Section. It was fabricated by Mr. Kenneth C. LaBau in the Space Sciences Division Model Shop.

The prototype assembly is shown in Figs. 1 and 2. The instrument as shown, without external electronic controls, weighs about 6 lb. A television assembly and ancillary electronics would weigh about 9 lb; thus, a complete flight instrument would weigh about 15 lb.

The microscope includes the following three functional subsystems:

(1) The sample-handling subsystem consisting of:

(a) A particle-size separator.

(b) A particle-encapsulation mechanism.

(c) A rotating slide stage.

(2) The optical subsystem consisting of:

(a) A light source.

(b) A narrow-band (10 mμ) filter at about 550 mμ (set to match peak spectral response of television camera).

(c) A polarizer.

(d) A substage condensing lens.

(e) Two refracting objective lenses.

(f) A step-focusing mechanism.

(g) An eyepiece lens.

(3) Imaging subsystem consisting of:

(a) Neutral-density filters and analyzer.

(b) A television camera.

The instrument is mechanically preprogrammed in three phases of operation. The first processes the sample particles, the second encapsulates them, and the third passes them through the field of view of the objective lens.

A particulate sample produced by an independent sampling system is poured into a metering cup which has a capacity of 1 cm^3; excess material spills over the edges and drops clear of the instrument. The operation starts with the rotation of the cup 180 deg to drop the sample into the processor through the funnel. The processor is a three-chambered enclosure oscillated by a 1/4-in. crank driven by the processor motor at 1600 rev/min. A diagram of the processor is shown in Fig. 3.

The sample is introduced to the chamber nearest the fixed axis of oscillation and migrates toward a 300-μ screen separating the second chamber from the first. Since the screen is installed at a 45-deg angle, the oscillations cause violent impingement of the particles on the screen, forcing particles smaller then 300 μ through the screen. In a similar manner, particles less than 60 μ are forced through the fine screen separating the third chamber from the second. Particles are accelerated at several earth g's, so that operation in a low gravity field, or at some tilt angle, will not be affected.

Each chanber has a rectangular port sealed with an elastomer-faced cover which seals the port during the sorting operation. After two minutes of sorting, the port of the fine-grained chamber is opened by a toggle linkage which first releases the spring pressure sealing the cover, then pulls the cover back clear of the port. The oscillating motion propels the specimen particles upward through the port to impinge on a glass slide which is coated with a thin film of thermoplastic (Zerlon). Zerlon is a methyl-methacrylate styrene copolymer made by the Dow Chemical Company. The plastic has been preheated to its softening point; the impinging material sticks to the slide in a single layer, all excess material falling away. At the same time, the port at the bottom of the first chamber opens discarding all material larger than 200 μ. After another 2 min, the port of the coarse-grained chamber opens, coating a second slide in a similar manner.

The material which was retained by the 300-μ screen is then purged from the chamber, and a second sample is delivered to the hopper. Two more slides are made from the second sample in the manner described above. The method by which the particles are encapsulated is shown in Fig. 4.

The slides are mounted on the turntable shown in Fig. 5 at four stations 90 deg apart. The upper glass plates are mounted on shuttles which shift them radially between a filling position and a viewing position. The filling positions align the slides with the ports of the processor; the slides for the fine samples are filled at a 1.45-in. radius, and the slides for the coarse samples are filled at 2.25-in. radius. The viewing position for all slides is at 185-in. radius. Fixed cams at the center of the turntable shift the slides to the filling position when they are indexed to the processor, and to the viewing position when indexed to the objective lens, which is 180 deg from the filling position.

The lower glass plates are retained in pockets in the turntable at the viewing radius. Each plate has a 0.030-in. layer of Zerlon bonded to the upper side and is spring-loaded against a pair of retaining bars which position it flush with the upper surface of the turntable.

Heaters, using nichrome wire encapsulated in a block of RTV 108 Silicone potting compound molded to the shape of the slides, supply the heat for melting the thermoplastic (Zerlon). The upper heaters are spring-loaded against the upper glass plates when they are at the filling position and provide heat to the appropriate plate during each 2-min processing period. The lower heaters are mounted at a station 90 deg beyond the viewing station and provide the heat for bonding the lower slides to the upper ones.

Each 2-1/2 min, an indexing sequence is initiated, in which the following events take place:

(1) Open the processor port and eject particles.

(2) Lift heater from contact with upper plate.

(3) Close processor port.

(4) Index turntable 90 deg to viewing position.

(5) Take one TV picture.

(6) Drop heaters to contact next upper plate.

This sequence is executed in 20 s.

A picture is taken in order to determine whether a satisfactory specimen has been deposited on the slide. If the slide is satisfactory, a pulse is initiated by ground control to accept the slide by actuating a solenoid, which releases a lower glass plate, permitting it to bear against the upper plate and thereby locking the shuttle in the viewing position. If the specimen is unsatisfactory, the acceptance pulse is not sent, and the upper plate is returned to the filling position on the next turn of the turntable for another attempt.

Each time the solenoid is actuated, it advances the programming ratchet one notch. After the fourth actuation (when all of the specimens have been accepted), the system is shifted to the phase in which the four samples are finally encapsulated.

The substage optical subsystem contains a light source, a narrow-band filter, a polarizing filter, and a condensing lens. An incandescent bulb is being used with a Baird-Atomic interference filter. An interference filter must have a half-width of less than about 14 mμ in order to produce sharp interference bands on a black-and-white TV. The wavelength desired from the scientific point of view can be anything that is shorter than about 530 mμ and that is compatible with the peak response of the imaging system employed. The General Electrodynamics Corporation vidicon which has been used in testing has a peak spectral response at 550 mμ.

The polarizer has been made of Polaroid Corporation's KN-36, a neutral linear polarizer on a polyvinyl alcohol base. Sheets of KN-36 have been treated and cooled in moderate vacuum (10^{-6} torr) in partial lunar environmental tests. The KN-36 sheets in a cross-polarizing position polarize very effectively in the 500- to 500-mμ range but not nearly as effectively in blue or red wavelengths.

The condensing lens produces an apical angle of about 20 deg. This convergence is not meant for conoscopic observation; it is only to increase the surface relief of transparent particles in the sample and to enhance the Becke line effect. Objective lenses of 16X and 40X are employed with a low-power eyepiece to view the coarse-grained and the fine-grained slides, respectively.

Six pictures are obtained of each field of view. Pictures are taken both below and above the plane of correct focus in order to change the positions of Becke lines, allowing an estimate of refractive index to be made. Each picture is taken in both plane-polarized and cross-polarized light. A maximum number of fields of view is made available by shifting the turntable radially, thereby obtaining four fields of view across the width of the slide. The turntable is indexed tangentially at the end of each radial scan. Eighty-eight fields of view will be available on each slide, providing 528 pictures for each.

If a vidicon is used as the television camera, the electron optics in the vidicon system determine the resolution of the final images. The diameter of the scanning spot in the vidicon tube is about 25 μ and probably cannot be made smaller. The desired final resolution therefore determines the total optical magnification to be used before the image is displayed on the vidicon faceplate. As an example, in order to determine the shape of a grain, eight to ten separate scans across the grain must be made. Because the scanning spot is 25 μ wide, the image on the faceplate must be 200 to 250 μ across. If the actual size of the grain is 10 μ, the optical image magnification must be 20X to 25X.

The processor motor and the heaters dissipate a total of about 12 Wh during the processing and encapsulating phases. The viewing phase requires about 3 Wh plus the television requirements. The peak power output required is 50 W in 1-s pulses for the solenoid. The total power required to obtain TV images and read them out prior to transmission to earth depends upon the type of mission; for the moon it is about 12 W average power. The bandwidth available to lunar missions will be about 250 kHz, which is about enough to transmit one 600-line TV frame per second. The power required for transmission to earth is about 50 W peak input power; images can be obtained about once every 4 s meaning that the average power required for transmission is about 13 W.

A lunar operation on an unmanned lunar soft-landing mission would entail encapsulating four samples and obtaining about 2200 TV pictures. A picture is transmitted in 1 s; therefore 2200 s of transmitting time is needed. The time between successive pictures depends upon the erase and readout times of the camera. During the erasure time for the microscope camera, data from other experiments could be transmitted. On these bases, the total operation time for an unmanned lunar microscopy experiment would be 1 to 2 h plus whatever extra time might be dictated by the quality and interest of the data. The total power expenditure would be less 40 Wh.

Functional testing of the prototype instrument has shown that all components are meeting their design specfications except the heaters. The heaters are not as efficient as desired, and will be replaced. The environmental testing program was not carried out because of a 2-mo delay during fabrication and a lack of necessary funds late in the fiscal year.

PUBLICATIONS DURING REPORT PERIOD

Meetings and Symposia Papers

1. Loomis, A. A., "A Lunar and Planetary Petrography Experiment," presented at the American Astronautical Society Meeting in Boston, May 25-27, 1967.

ANTICIPATED PUBLICATIONS

None.

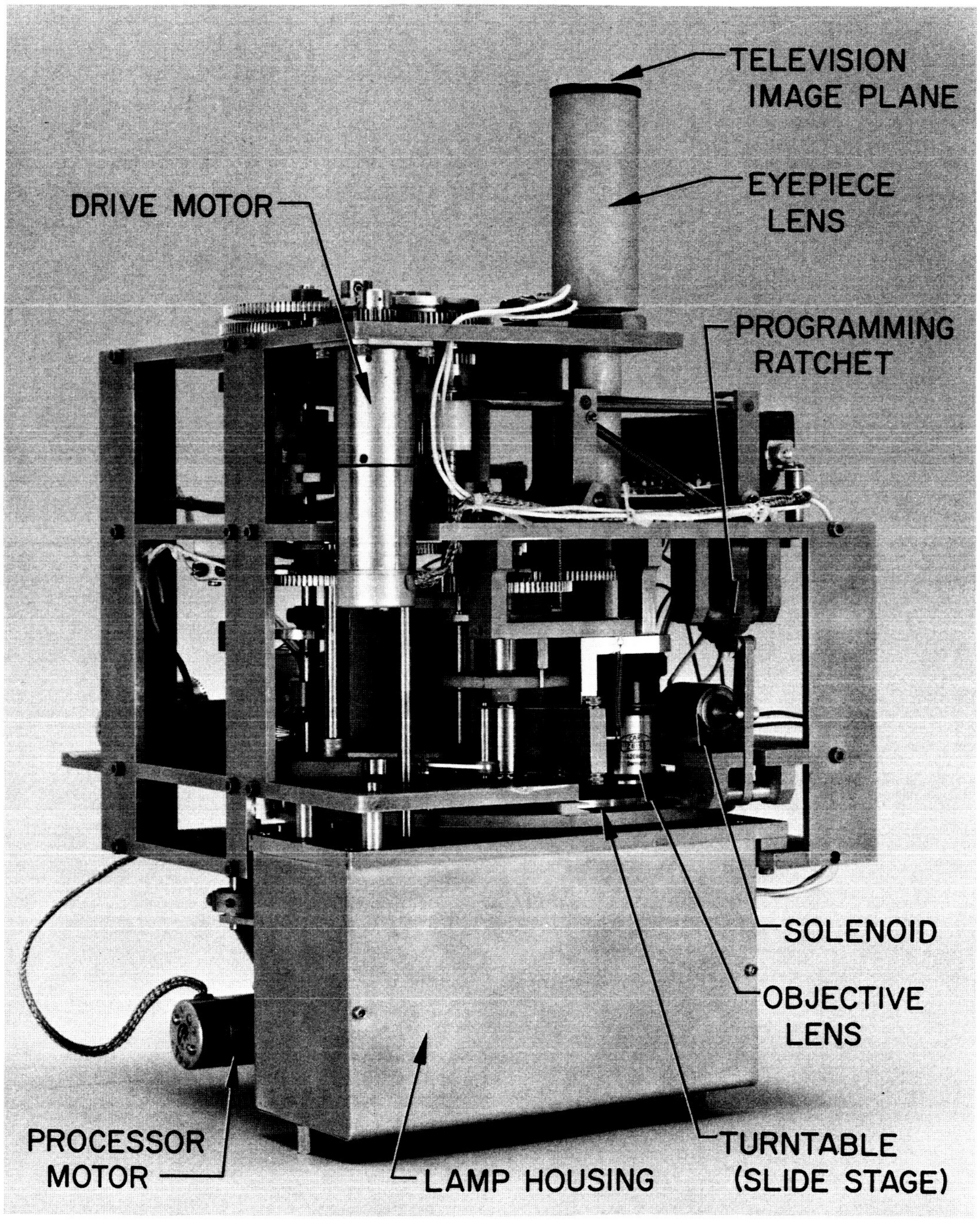

Fig. 1. Engineering prototype assembly, side view

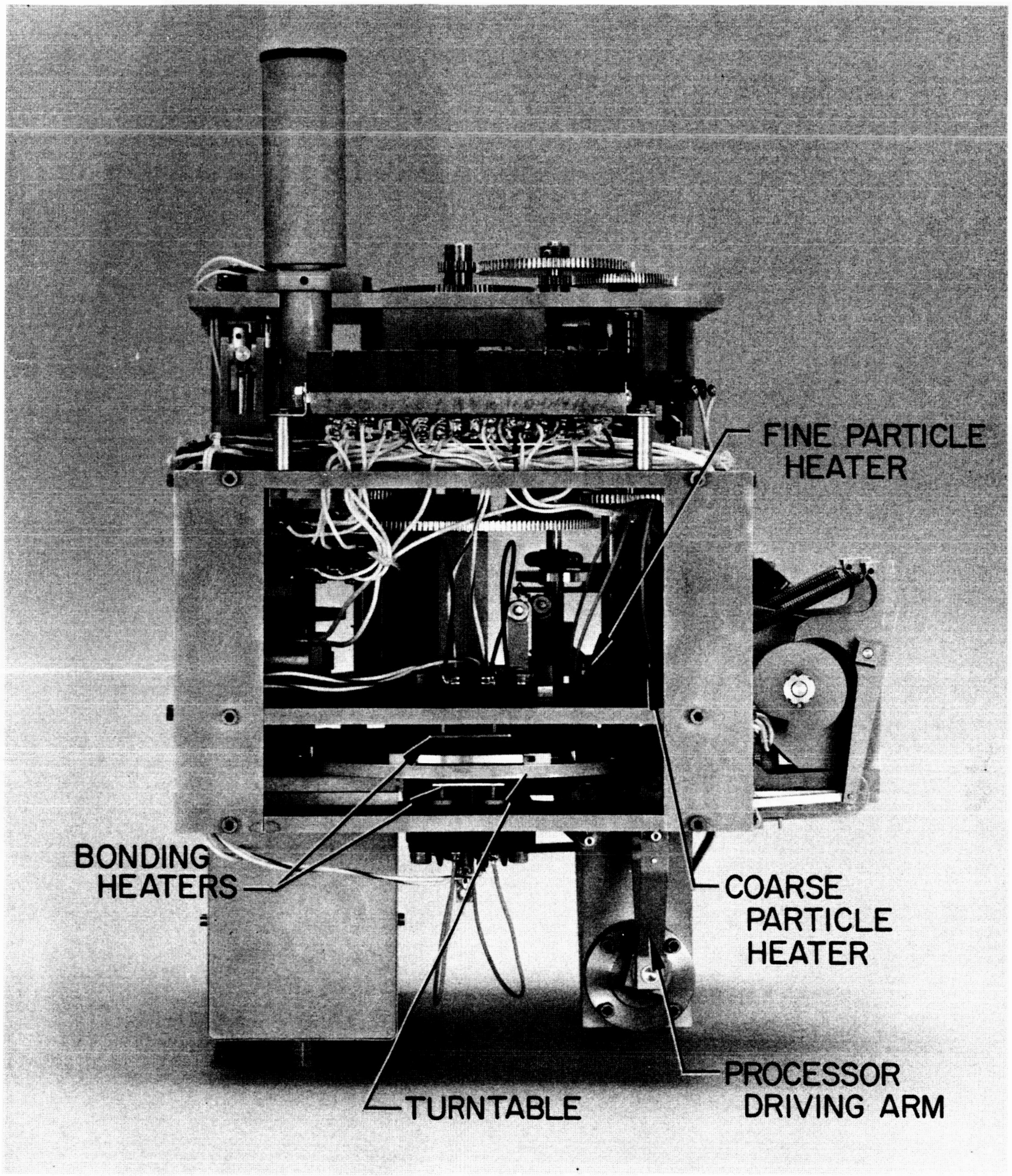

Fig. 2. Engineering prototype assembly, front view

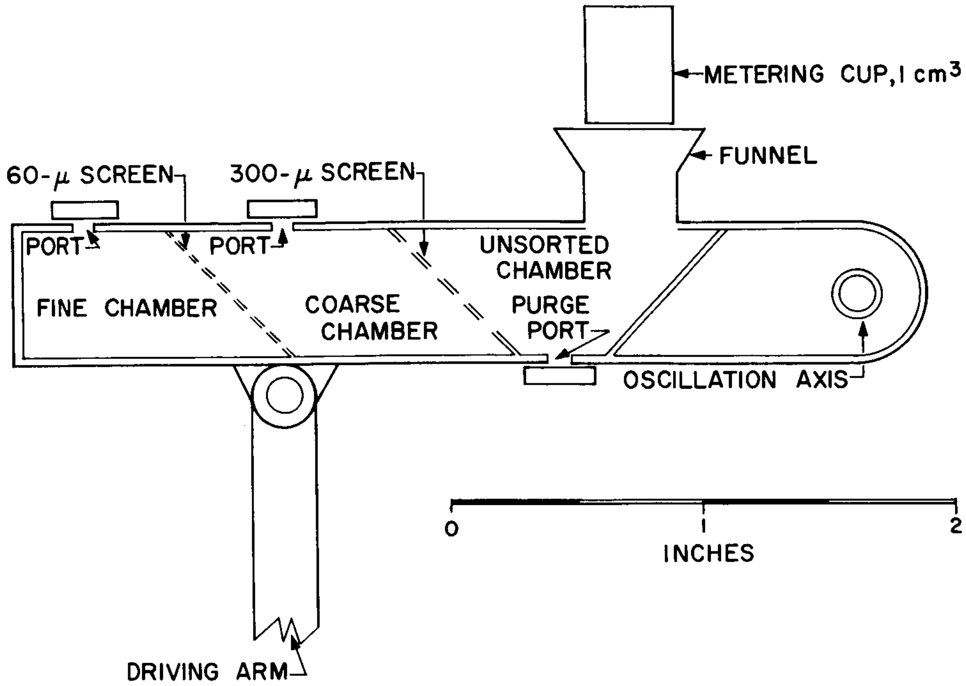

Fig. 3. Schematic diagram of processor

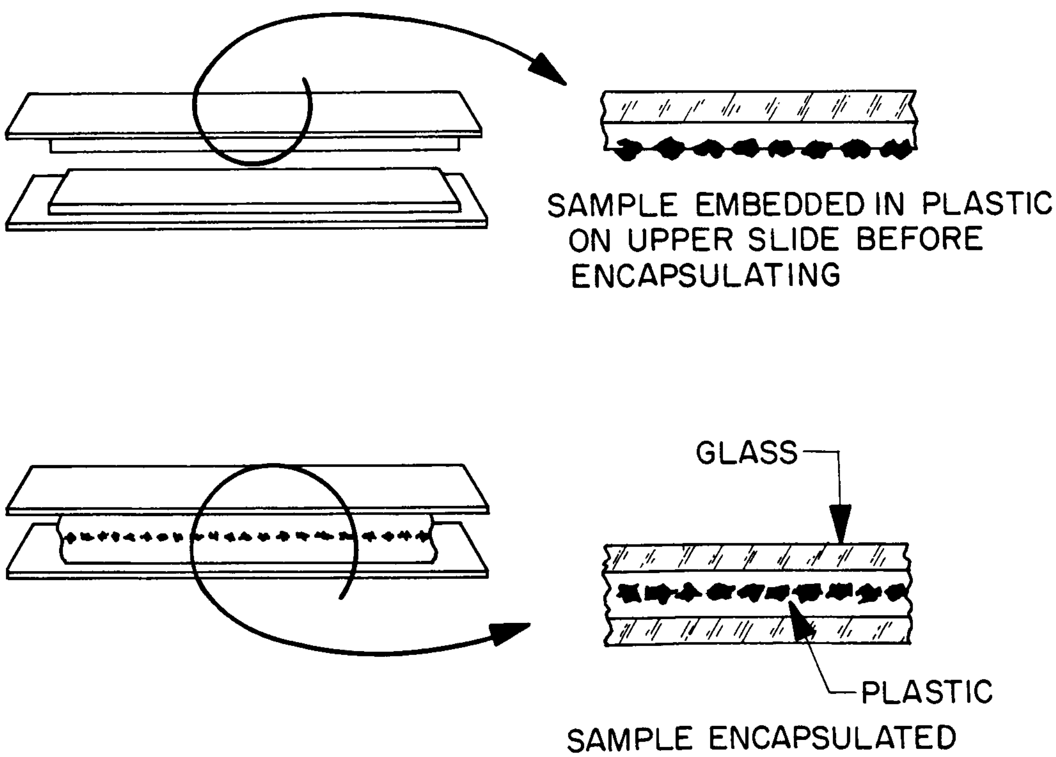

Fig. 4. Schematic diagram of encapsulation procedure

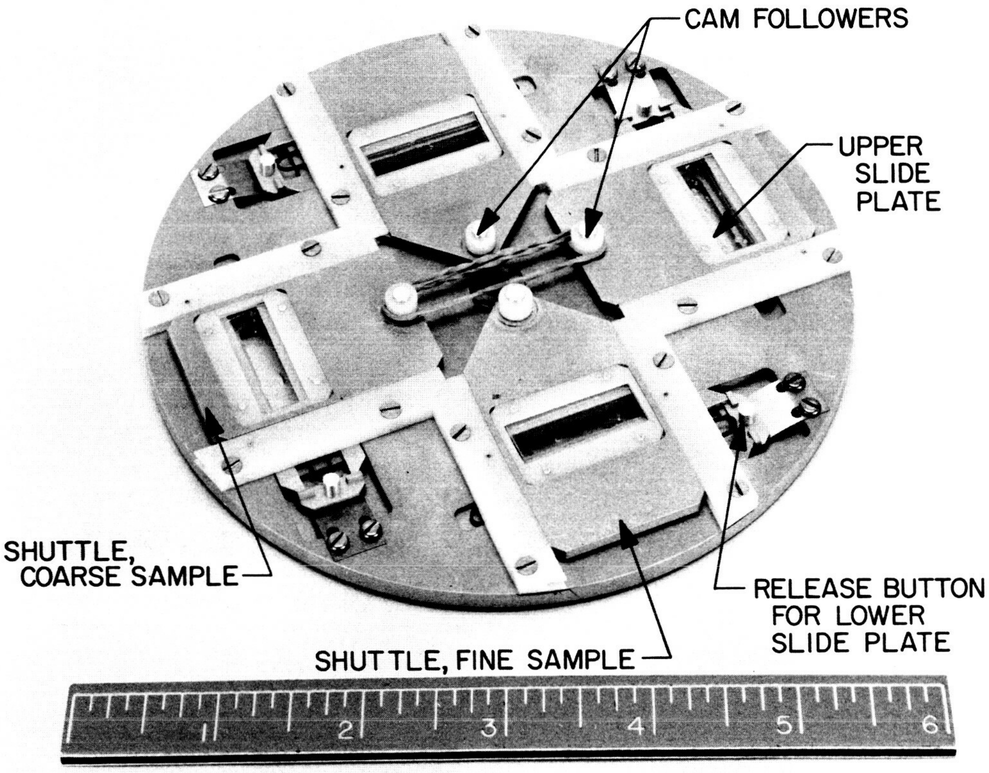

Fig. 5. Turntable (slide stage)

INFRARED EMISSION OF SILICATES
NASA Work Unit 185-42-20-20-55
JPL 383-20501-2-3250

J. E. Conel

OBJECTIVE

This program involves laboratory and theoretical investigations of fundamental problems in application of the infrared emission technique to the study of planetary surface petrology and composition.

PROGRESS

During the current report period, approximately 150 emission spectra were obtained of some 45 common rocks and rock-forming minerals, both solid and granulated. These results confirm earlier experimental conclusions:

(1) Granulation reduces but does not remove spectral contrasts.

(2) Apparent shifts in emissivity minima occur in certain cases with roughening and granulation, especially in complex assemblages, but are almost never observed in spectra of single minerals.

In addition, under certain circumstances a new effect was noted in the emission spectra of the finest granulated fractions (particle sizes $\leq 37\mu$). Figure 1 shows the spectral normal emissivity of quartz of various size fractions. The topmost curve for the finest (tightly packed) material contains most of the structure of the others, and an additional minimum near 11μ. It is tentatively suggested that this feature arises from the combined effects of scattering from the specimen surface and of the optical properties of quartz near 12μ. With certain rocks (basalts) such scattering effects may actually dominate those due to absorption, thus producing a spectrum with somewhat anomalous structure.

The latter part of April and the month of May were spent with the Surveyor Lunar Thermal Properties Group analyzing temperature data from Surveyor III to determine lunar surface temperatures and thermal properties. The results will appear as Section VI of the Surveyor III Mission Report, a paper co-authored with others from JPL, Hughes Aircraft, and Boeing Scientific Research Laboratories.

PUBLICATIONS DURING REPORT PERIOD

Open Literature

1. Lucas, J. W., Conel, J. E., and Hagemeyer, W. A., "Lunar Surface Thermal Characteristics from Surveyor I," J. Geophys. Res., Vol. 72, No. 2, January 1967. Presented at AIAA Thermophysics Specialists Conference, New Orleans, April 17, 1967.

JPL SPS Contribution

1. Conel, J. E., "Effects of Thermally Nonuniform Sources on Emission Spectra of Silicates," SPS 37-43, Vol. IV, p. 299, February 1967.

ANTICIPATED PUBLICATIONS

Meetings and Symposia Papers

1. Conel, J. E., "Thermal Emission Spectroscopy; A Method for Remote Compositional Analysis of Planetary Surfaces," to be presented at Joint Convention of American Chemical Society and Society of Applied Spectroscopy, Anaheim, California, October 1967.

JPL Technical Report

1. Conel, J. E., An Experimental Evaluation of a Method of Remote Petrologic Analysis, Part I: Infrared Emission Spectra of Polished and Granulated Silicate, TR in preparation, 1967.

2. Lucas, J., Conel, J. E., et al., Lunar Temperatures and Thermal Characteristics (Surveyor III) From Surveyor III Mission Dept. (to be published as NASA SP).

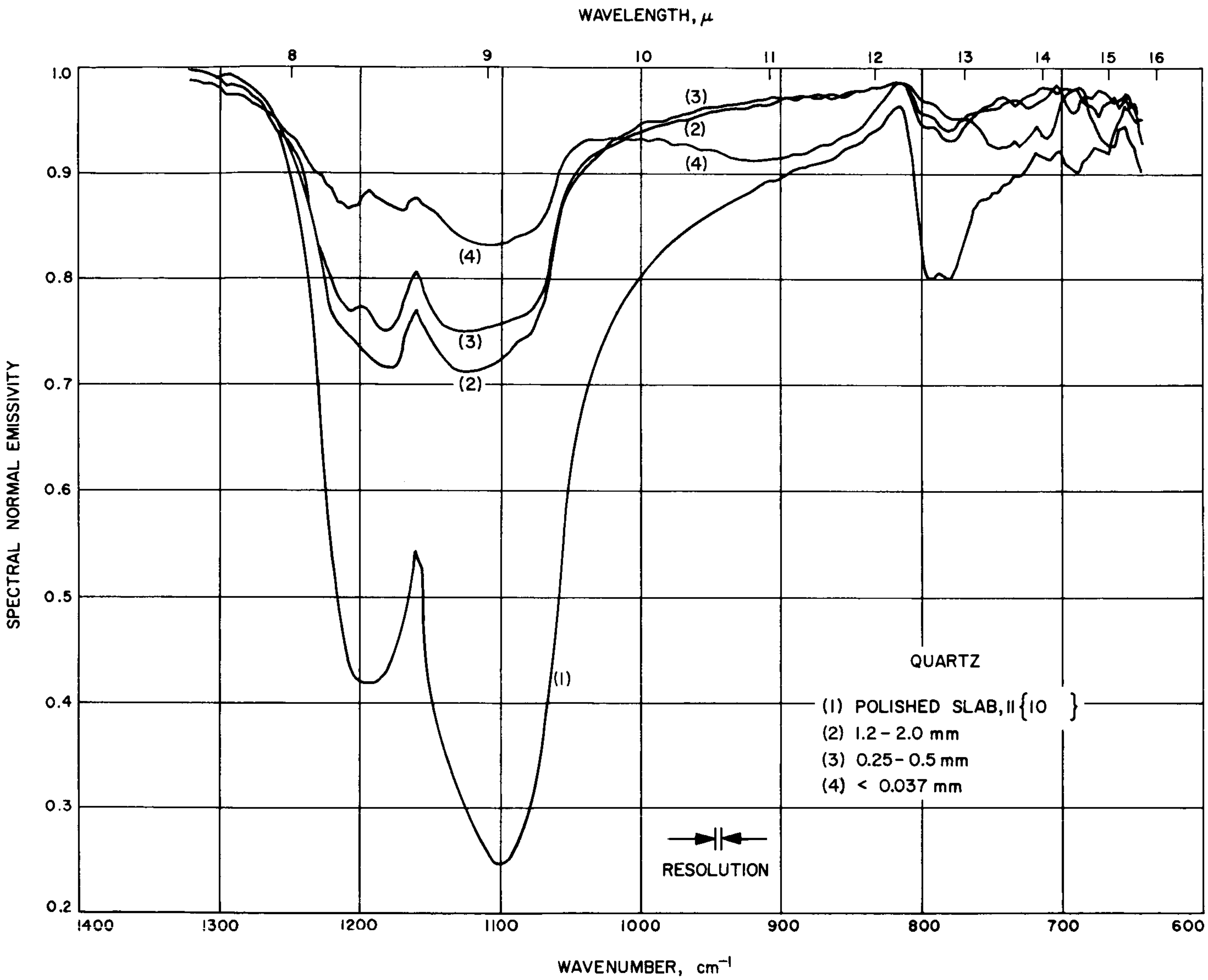

Fig. 1. Spectral normal emissivity of quartz

PLANETARY ATMOSPHERES (185-47)

INFRARED MULTIDETECTOR RADIOMETER

NASA Work Unit 185-47-26-01-55
JPL 383-70301-2-3230
383-70302-2-3250
D. LaPorte

OBJECTIVE

The objective of this task is to complete the feasibility demonstration of the infrared temperature-sounding experiment proposed for the Apollo Applications Program. For this experiment it is proposed to use a multidetector radiometer to measure the radiation emitted by the earth's surface and by CO_2 in the atmosphere near 4.3 μ. Analysis of this radiance distribution will give the desired temperature profiles. An extension of the experiment using this instrument to measure radiation between 2.0 and 3.5 μ with higher resolution has since been proposed. These data are to be analyzed to determine cloud heights, surface elevations, water vapor distribution, and abundance of gases of biological importance (e.g., methane and nitrous oxide). This latter extension is considered as a possible tool in probing the Martian atmosphere at some future date.

TEMPERATURE SOUNDING FEASIBILITY STUDY

In order to demonstrate the feasibility of performing the temperature sounding, a balloon flight had been proposed with an engineering model of the Apollo instrument for the last quarter of FY 1966. This flight did not take place because of a failure in the balloon launching process. Funding to initiate a second attempt in FY 1966 was received from the Manned Satellite Science Office but was insufficient to carry the activities to completion.

At the beginning of the second quarter of the present fiscal year, funding to complete the balloon activities and the short-wavelength studies was received under the present task. During December 1966 and January 1967 calculations were completed and the results are shown in Table 1.

On February 19, 1967, a balloon flight was successfully completed from Page, Arizona, and very good radiance data was obtained from both the multidetector radiometer and the "reference" scanning radiometer. The radiance data are shown in Fig. 1. Note the excellent agreement between the two types of instruments.

A "quick look" temperature inversion was computed and the results are shown in Fig. 2. Further calculations show improvement over that shown and will be presented in future publications.

A milestone chart (Fig. 3) indicates the only task left to be performed under this work unit is the completion of the data analysis.

The remaining tasks under "Cloud and Surface Height Experiment" are being performed under another work unit and will be reported elsewhere.

PUBLICATIONS DURING REPORT PERIOD

Open Literature

1. Shaw, J. H., McClatchey, R., and Schaper, P. W., "Balloon Observations of the Radiance of the Earth Between 2100 cm^{-1} and 2700 cm^{-1}," Appl. Opt., Vol. VI, No. 2, p. 227, February 1967.

JPL SPS Contributions

1. Schaper, P. W., "An Infrared Multidetector Spectrometer for Absolute Radiometric Measurements," SPS 37-43, Vol. IV, February 1965.

2. McClatchey, R., "An Experiment for the Determination of Surface and Cloud Top Elevations," SPS 37-44, Vol. IV.

ANTICIPATED PUBLICATIONS

JPL SPS Contributions

1. Shaw, J. H., and Schaper, P. W., "Surface Temperature of Mars," SPS 37-45, Vol. IV.

Table 1. Instrument parameters

Detector no.	Wavelength, μ	Black Body Temperature							
		280°K		260°K		240°K		220°K	
		Error, % [a]	S/N	Error, % [a]	S/N	Error, % [a]	S/N	Error, % [a]	S/N
2	3.711	3.7	357	2.6	126	0.4	41	7.2	9
13	4.182	4.2	1080	2.1	440	0.9	158	5.7	40
14	4.220	3.9	1450	3.2	596	0.9	217	1.0	56
15	4.264	3.2	1370	2.0	582	1.5	214	-	56
16	4.308	3.0	2560	1.8	1065	0.7	397	4.0	104
17	4.346	2.8	2220	2.1	879	1.3	329	3.8	88
18	4.384	3.0	2030	2.0	860	1.2	325	2.8	88
19	4.423	2.7	2450	1.6	1040	2.0	398	6.0	109
35	5.009	2.5	1660	1.8	782	1.5	333	2.5	106

[a] $\text{Error} = \left[\dfrac{\text{Measured Black Body Radiance}}{\text{Calculated Black Body Radiance}} - 1\right] \times 100\%$

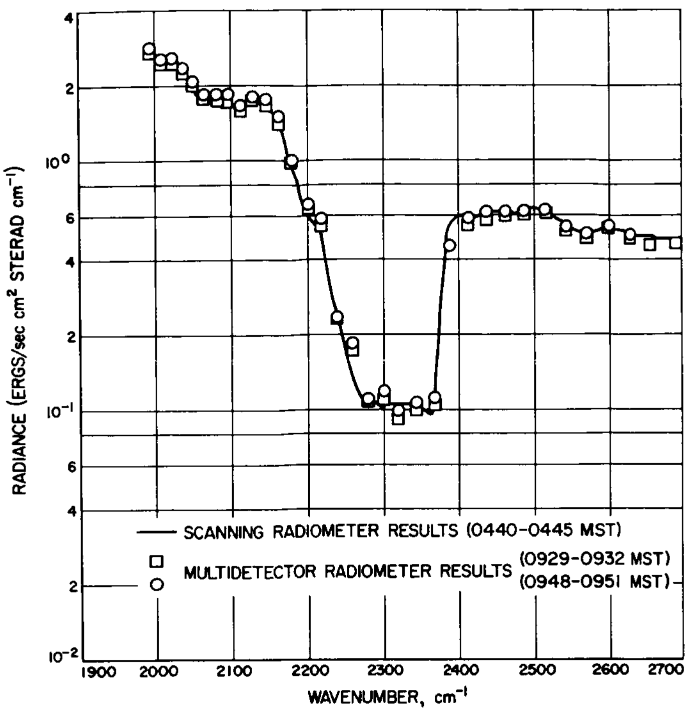

Fig. 1. Balloon flight radiance data

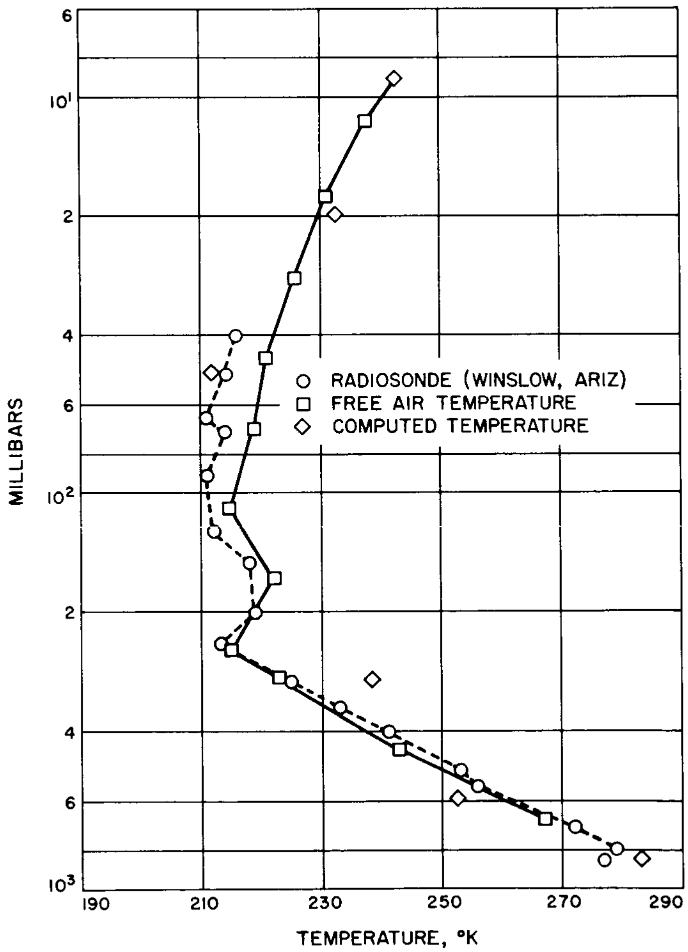

Fig. 2. Temperature inversion results

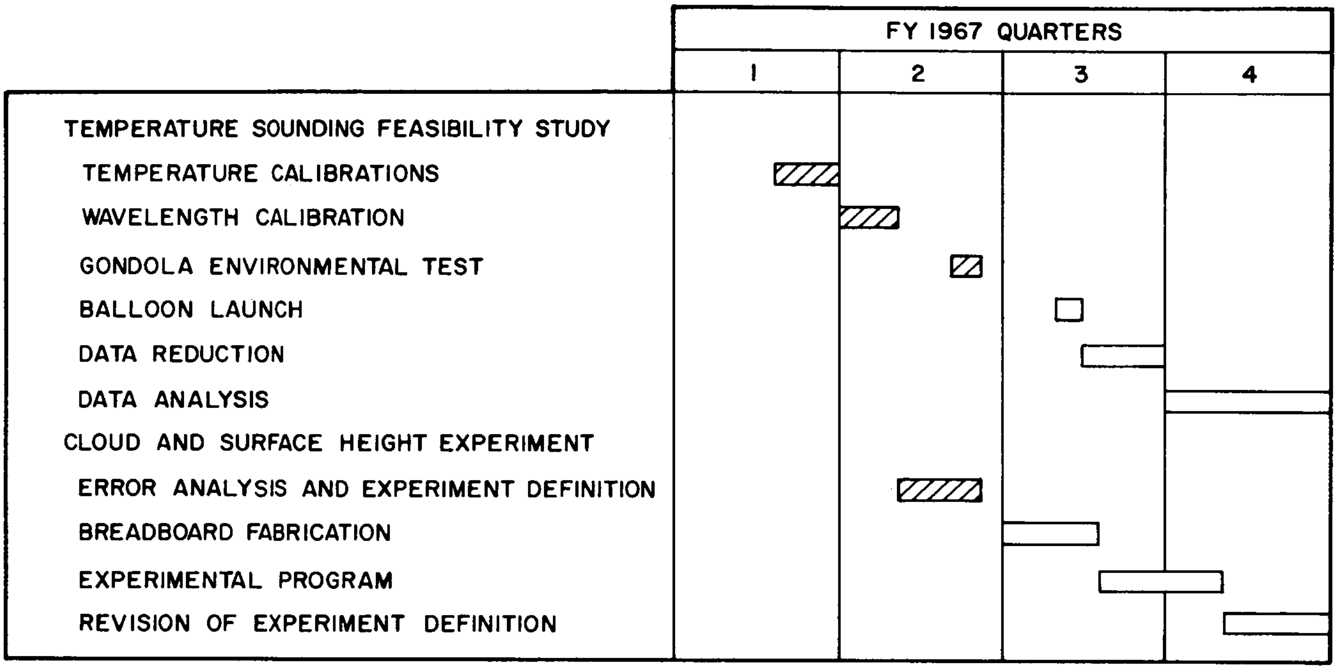

Fig. 3. Milestone chart for IR multidetector radiometer

MODEL ATMOSPHERES
NASA Work Unit 185-47-26-02-55
JPL 383-70201-2-3250
R. A. McClatchey

OBJECTIVE

The objective of this work unit is to establish the physical parameters that define the atmospheres of Mars and Venus, making use of both experimental observations and theoretical calculations. Theoretical support will be given to the Mars infrared experiment including the temperature sounding experiment; additional effort will be expended toward understanding the general atmospheric circulation of Mars; methods for the analysis of planetary spectra will be further developed.

PROGRESS

Analysis of Absorption Measurements

L. Gray (on leave of absence at the University of Texas until August 1967) has been analyzing the 1.25 to 2 μ spectrum of Venus obtained by P. and J. Connes during July 1966. The data contain approximately 100 vibration-rotation bands of CO_2, each having an average of 50 rotational lines. To date, 12 bands of CO_2 have been identified that have never been observed before, either in the laboratory or in the earth's atmosphere. Their appearance in the Venus spectrum is a result of the large amount of CO_2 in the Venus atmosphere. In addition, 5 bands of CO_2 have been observed for the first time at sufficiently high resolution that the individual rotational lines are resolved. For these 17 bands, L. Gray and J. Connes are finding the values of spectroscopic rotational constants, which are vital to our knowledge of the CO_2 molecule. J. Connes and L. Gray are also in the process of preparing a computer program to calculate equivalent widths of lines in selected CO_2 bands. This will allow a determination of isotopic abundances of $^{13}C/^{12}C$, $^{18}O/^{16}O$, and $^{17}O/^{16}O$ as well as average temperatures in the atmosphere of Venus. Preliminary measurements indicate that the isotopic abundances are the same for Venus as for earth, but the accuracy of these is about 50%. In addition, the temperature at the level of line formation appears to be 240°K, but a more accurate value requires computer calculations now in preparation.

L. Gray has been working with R. Schorn on the interpretation of Venus spectra at 1.05 μ. Here the variation of the equivalent width of CO_2 lines with Venus phase angle (the angle between the earth and the sun as viewed from Venus) was studied. An attempt was made to determine the variation with wavelength of the scattering properties, and to determine the curve-of-growth for CO_2 lines formed in the Venus atmosphere. A weak "hot" band of CO_2 was observed and used to a temperature of $T = 225 \pm 25$°K. This temperature appeared to be independent of the phase angle. Based upon a "reflecting layer" analysis, Gray and Schorn found an upper limit to the amount of CO_2 of 1.5 km atm, which agrees with results obtained for the 7800 and 8700 A CO_2 bands using the same method of analysis. Gray and Schorn have been making further observations (photographic infrared) of Mars in order to determine the abundance of CO_2 in that atmosphere more accurately.

They hope to complete the analysis of the Venus spectrum in the next six months; that is, to obtain the amount of CO_2 (or the mixing ratio), the temperature, isotopic abundances, and spectroscopic constants for the recently discovered CO_2 bands in the Venus atmosphere. When this is completed, the long-term program of calculations of CO_2 transmittance will be resumed. Gray and Schorn will continue to observe Mars and Venus in the photographic infrared.

A theoretical study was undertaken by R. McClatchey (now at Avco, Lowell, Mass.) to establish the effect of a scattering atmosphere on the formation of absorption lines. The objective was a method for examining spectral features in the Venus atmosphere and inferring the mixing ratio of CO_2 (or other gases) and the level of line formation. The assumption of a simple reflecting level has led to conflicting results from different absorption bands. It has been found that the equivalent widths of spectral lines depend on the ratio of the mass of absorbing gas to the scattering optical depth in the linear portion of the curve-of-growth and on the mp product divided by the square of the scattering optical depth in the "square root" portion. This allows the determination of the mass mixing ratio of the absorbing gas but does not define the level of line formation.

The fact that a linear portion of the curves-of-growth was obtained appears to be in contradiction to some earlier work of Chamberlain and Kuiper, who obtained as a weak line limit in a scattering and absorbing atmosphere a square root dependence of absorption on line intensity. An examination of their work was made, and it was discovered that this weak-line square root law is only valid when the planetary albedo is strictly unity. If the planetary albedo is anything else, the asymptotic weak-line limit is a linear dependence. The results of this work have been published as a letter in the Astrophysical Journal.

More fundamental work on radiative transport and line formation will be undertaken in FY 1968 by A. Fymat, who has replaced R. McClatchey.

The 1- to 5- μ Infrared Experiment

This experiment has been devised as an expansion of the 4.3 μ CO_2 band temperature sounding experiment utilizing the same spectrometer. The experiment as now conceived will perform the following measurements from a Mars flyby or orbiting platform:

(1) Study of the reflection spectra of polar caps and cloud or haze layers in the 1- to 2- μ region in order to make a composition determination. Laboratory reflection spectra of CO_2 and H_2O ice have been obtained by John Adams (JPL) on a Beckman DK2A spectrometer.

(2) Measurement of the absorption of solar radiation reflected from the planetary surface in the 2- and 2.7-μ CO_2 absorption bands. Such a measurement will provide a surface or cloud-top elevation determination, a determination of planetary oblateness, and an indication of pressure changes associated with polar cap formation or disappearance.

(3) Quantitative measurement of other gases thought to be present in the Martian atmosphere, such as H_2O, CO, CH_4, and any others having absorption features in the 1- to 5-μ region.

(4) Determination of the vertical temperature structure of the atmosphere by measurements of absolute radiance in the 4.3-μ CO_2 band.

(5) Determination of surface temperature and emissivity of the ground by measurements of radiance near 5 μ.

Item (2) has been examined in some detail and the results incorporated in a JPL SPS article. Calculations have been made for the transmittance of the 2- and 2.7-μ CO_2 bands for different values of the partial pressure of CO_2. A difference of 1 mb at 8 mb corresponds approximately to 1.5 km of elevation difference. It is reasonable to state that 1-km elevation differences could be differentiated on Mars. The spatial resolution is limited by the telescope used and by the closest approach of the spacecraft. A 1-deg field of view at 1000 km would yield a spatial resolution of about 20 km. From an orbiter, temporal and spatial correlations of the absorption would be determined. Such correlations are related to moving "weather" systems, to tidal effects, and to planetary oblateness. The removal of these effects will improve the elevation determination.

PUBLICATIONS DURING REPORT PERIOD

Meetings and Symposia Papers

1. McClatchey, R. A., "Remote Sensing of the Atmospheric Temperature Profile from Satellites," AIAA local meeting, invited paper January 10, 1967.

Open Literature

1. Shaw, J. H., McClatchey, R. A., and Schaper, P. W., "Balloon Observations of the Radiance of the Earth, 2100-2700 cm^{-1}," Appl. Opt., 6, February 2, 1967. (JPL SPS 37-44, Vol. IV, p. 217, March 1967.)

2. Schorn, R. A., and Gray, L. D., "The Martian Surface Pressure," Astrophys. J., Vol. 148, No. 2, pp. 663-664, May 1967.

3. McClatchey, R. A., "A Weak-Line Absorption Law in a Semi-Infinite Homogeneous Scattering Atmosphere," Astrophys. J., Vol. 148, No. 2, pp. 193-195, May 1967.

JPL SPS Contribution

1. McClatchey, R. A., "An Experiment for the Determination of Martian Surface and Cloud-Top Elevations," SPS 37-44, Vol. IV, March 1967.

ANTICIPATED PUBLICATIONS

None.

ADVANCED TECHNICAL DEVELOPMENT (186)

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PLANETARY QUARANTINE/STERILIZATION (186-58)

STERILIZABLE PHOTODECTECTORS

NASA Work Unit 186-58-02-02-55
JPL 384-82501-2-3440

J. M. McLauchlan

OBJECTIVE

The objective of this work unit is to develop a sterilizable photocathode for the all electrostatic image dissector (ID) tube. The specific photocathode being developed is a bialkali type containing no cesium.

HIGH TEMPERATURE PHOTOCATHODE IMAGE DISSECTOR

Since the Mariner IV Canopus sensor has shown that the ID tube is a superior detector where high sensitivity, long life, and ruggedness are important, it has many potential applications. For example, in the exploration of Mars it could be used as a star sensor, approach guidance planet sensor, landing guidance sensor, or as a low-bit-rate, low-power, long-life TV. Some of the applications would require that the ID tube be capable of withstanding ethylene oxide decontamination and heat sterilization. A bialkali photocathode instead of a cesium (S-11) photocathode was chosen since it was believed that it would better withstand both treatments. Since a photomultiplier tube is relatively inexpensive compared with an ID tube, they are being used to develop the proper technique for producing sterilizable bialkali photocathodes for ID tubes. In addition, since both the sterilizable work and the continuing improvement of ID tube characteristics (NASA Work Unit 186-68-02-19-55) concern the same tube, the effort has been combined into one contract with CBS Laboratories.

PHOTOMULTIPLIER TUBE PROCESSING

Since the ID tube is a sealed unit, ethylene oxide decontamination creates no problems; however, heat sterilization does in that it deteriorates the photocathode properties. The contractors efforts have included the fabricating of photomultiplier tubes which are made in exactly the same manner and contain the same materials as the ID tube.

Experimental photomultiplier (PM) tubes built during this period have indicated that the bialkali photocathode, being developed to withstand sterilization temperatures, is feasible. A problem is that although the PM s can be made to go through a sterilization cycle with small changes in sensitivity (approximately 10%), their initial sensitivity is low (about 25 μ A/lm) and photocathode uniformity varies considerably.

Some improvement in photocathode uniformity has been obtained by changing the geometry of the PM s so that the photocathode materials are deposited more uniformly.

PLANNED FOR NEXT PERIOD

The completion of the present contracted work will end this task as no additional work is intended beyond the end of FY 1967.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Herman, D. S., "Image Dissector Tube Development," SPS 37-42, Vol. IV.

ANTICIPATED PUBLICATIONS

Contractor Reports

1. Final Report, Improvement of Image Dissector Tube, CBS Laboratories.

INERTIAL SENSOR STERILIZATION
NASA Work Unit 186-58-02-03-55
JPL 384-82701-2-3440
P. J. Hand

OBJECTIVE

The objective of this work unit is to develop thermal and gas sterilization capabilities into the newest miniature inertial sensors which have potential applications in advanced spacecraft and capsule attitude control systems.

GYRO DEVELOPMENT

It is the intent of this portion of the work unit to develop the miniature, single-axis, gas-bearing gyroscope known as the Honeywell Inc. Model DGG 159, into a high-performance, low-power instrument capable of surviving six cycles of thermal sterilization at 135°C. Survival requires that neither catastrophic failure nor significant performance degradation shall take place as a result of sterilization.

Gas sterilization with ethelyne oxide and freon has not been found to be a problem as the instrument is completely hermetically sealed in order to operate in the space vacuum environment.

It was reported in the last semiannual review (JPL TM 33-322), that the DGG 159 D-2 S/N E 1 gyro had passed four sterilization cycles with a minimum of difficulty.

As of this report, June 1967, the instrument has received a total of seven sterilization cycles as well as the additional environments of vibration and 200-g shock testing.

The performance of the critical g-sensitive drift rate parameters during the seven sterilization cycles can generally be characterized as an immediate moderate shift followed by a gradual return to near the original drift value. The g-insensitive drifts were within the normal stability limits for this gyro during all sterilization cycles.

The vibration and shock tests caused much more severe shifts of the same drift parameters. The Mariner TA level vibration caused an input axis mass unbalance shift of 1.3 deg/h, while the TA shock test of 200 g caused a large shift in both spin axis and input axis mass unbalance. This shift was 1.9 deg/h for the IA and 28 deg/h for the SA. Both shifts are excessive and tend to indicate an abnormal condition within the gyro gimbal. The previous gyro of this series (the DGG 159 C-7) successfully passed the same vibration and shock tests with shifts within the specifications of ±0.25 deg/h.

Future plans for the 159 series gyros call for the delivery of one DGG 159 E type unit in March 1968. This instrument will contain, in addition to sterilization capability, all other JPL-funded improvements applicable to this design, such as high-frequency gimbal suspension pump, low-power spin motor, and 200-g motor.

The sterilization and environmental testing will all be performed at Honeywell, Inc. The contract for this gyro was released on January 3, 1967, for an amount of $67, 923.

As of June 1967, the first attempt at assembling the E Model gyro has shown some difficulties. The floatation fluid did not meet the vendor's specifications, causing erroneous values of gyro gain and damping and also an excessive value for optimum suspension pump frequency. Both of these deficiencies are being corrected by rebuilding these portions of the instrument.

STERILIZABLE SUBMINIATURE GYRO MOTOR EVALUATION

The objective of this portion of the work unit is to evaluate the thermal sterilization capabilities of the newest subminiature, precision gyro spin motor design. The recent reduction in sterilization temperatures from 145 to 135°C reopens the possibility of using ball-bearing gyros in sterilizable attitude control systems.

The gyro motor chosen is the Kearfott Alpha III design. The standard version of this gyro has been under evaluation at JPL for several months and has demonstrated a high probability of being successful. This gyro is approximately one-half the size and weight of existing miniature gyros. It also requires only about two-thirds the power of present instruments. It is therefore representative of the latest in design concepts in precision ball-bearing gyros.

Due to the high cost and long lead time associated with sterilization development programs on complete gyros, it was decided to evaluate the weakest known gyro part (from the thermal sterilization standpoint), namely the spin motor itself.

A contract is due to be released to Kearfott for the evaluation in the thermal sterilization environment of two complete motors, as well as critical piece parts. This is planned to be a 1-yr program.

If the evaluation indicates a satisfactory confidence level for the performance of the motors in sterilization, it will be proposed to follow on with a complete sterilizable gyro development program.

ACCELEROMETER DEVELOPMENT

The goal of this effort is to develop a miniature, high-accuracy accelerometer which is capable of withstanding six thermal sterilization cycles without either failure or significant performance degradation.

The accelerometer chosen for this development is the Bell Aerosystems Model VII. This is a linear, force-balance type presently used on the Apollo Lunar Module (LM) as well as several commercial inertial navigation systems.

A 1-yr contract was released to Bell Aerosystems in July 1966 for the development and fabrication of one sterilizable instrument. This contract is now in its eleventh month.

Two principal areas are under investigation: the mechanical pendulum structure and the pickoff electronics. The main problem in the mechanical area is finding an adhesive for the pendulum assembly which provides the necessary long-term stability combined with good heat-resistant properties.

Two attempts have been made to fabricate the mechanical assembly using different epoxies. The first unit degraded badly during the thermal soak, while the second unit developed a sticky pendulum assembly and had to be disassembled. During reassembly the suspension springs were broken, so the entire structure had to be rebuilt. At the present time the unit is ready to start the presterilization testing again.

The electronic assembly requires a critical pickoff transformer which has been redesigned to meet the high-temperature requirements. The remainder of the electronic assembly was to have been fabricated from JPL approved Hi-Rel parts, however, the parts vendors refused to supply parts in small development-type quantities, so alternative choices were made as near to the JPL-approved parts as possible.

The first version of a sterilizable unit is due at JPL in July 1967 for evaluation. At the present rate of progress, this schedule seems doubtful, and it is estimated that a 1-mo schedule slippage will be encountered.

A follow-on program is now under negotiation to extend the program another year, adding four more instruments and additional microminiature electronic rebalance loops.

STERILIZABLE SPRING RESTRAINED RATE GYRO DEVELOPMENT

This subject is not yet an approved work unit; however, recent system studies have shown an increasing need for rate gyro information for use in stabilizing a landing capsule.

In anticipation of this requirement, a letter of interest was circulated from the JPL Procurement Division to twenty-seven companies in the inertial sensor field, to find those companies interested in participating in a sterilization development effort. As of June 1967, eight vendors have returned an affirmative statement. If the work unit is approved, a 1-yr development program will be implemented with a competitive procurement action.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

STERILIZATION OF CAPSULE CONTROL SYSTEMS

NASA Work Unit 186-58-02-05-55
JPL 384-80301-2-3440

R. J. Mankovitz

OBJECTIVE

The objectives of this work unit are: (1) to help define components required for guidance-and-control subsystems on landing capsules, (2) to recommend new component developments when current mechanizations cannot be sterilized, (3) to assess compatibility of component and systems level sterilization requirements, and (4) to assess electronic components required for systems mechanizations to determine if new component qualification programs are required.

PROGRESS

Considering objective (1), Table 1 shows a summary of control system components and their sterilization status. All foreseeable components are in development, and this objective is complete.

Considering objective (2), two breadboarded circuits were developed to eliminate the use of signal transformers and large value capacitors. These circuits were subjected to six cycles of heat sterilization (135°C). Subsequent testing revealed no degradation in performance (reported in JPL SPS 37-43). In addition, the Mariner C type-approval attitude control subsystem has been subjected to heat sterilization (9 cycles at 145°C) with no degradation in performance. Several welded modules from the unit were cut apart, and no component degradation could be observed. The accomplishment of the above efforts was the final milestone in this objective.

During the development of alternate circuitry, it became obvious that circuit redesign from the point of view of sterilization was too narrow an approach for an Advanced Development task. It is more desirable to investigate and develop new control system electronics from an overall reliability concept, using techniques such as redundancy, automatic failure detection, etc. A new Advanced Development task is being proposed for the investigation of "Long Life and Reliability Control System Development" (NASA Work Unit 186-68-02-32-55).

If any requirements are identified in the future, in the area of sterilizable attitude control electronics, they will be included in the new task.

Considering objective (3), in determining if there are any problems in functionally testing a sterile system without sacrificing the sterile integrity, no unique problems exist in the area of attitude control electronics, which can be sterile-tested via external connectors. Any unique problems associated with actuator and optical and inertial sensor testing will be investigated under the individual component tasks.

Considering objective (4), parts qualification programs have been instituted for some of the components required in the breadboards described above. These components include: Philbrick Q 25AH, Q 85AH, microelectronic operational

amplifier; Fairchild C μL - 958, microelectronic decade counter; Fairchild μA-709, microelectronic operational amplifier.

FUTURE WORK

All objectives for this task have been completed, and the effort will be terminated at the end of FY 1967.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Mankovitz, R. J., "Sterilization of Capsule Control Systems," SPS 37-43, Vol. IV, p. 83.

ANTICIPATED PUBLICATIONS

None.

Table 1. Summary of capsule control system component sterilization

Component	Status
Wide-angle gyros	In development
Spring-restrained rate gyros	Development proposed for FY 1968
Jet-vane actuators	Existing hardware is suitable
Cold-gas jets	Existing hardware is suitable
Electronics	In development
Axial accelerometer	In development
Photodetectors	Being investigated
Image dissector	In development

STERILIZABLE SCIENCE DATA BUFFER

NASA Work Unit 186-58-03-02-55

JPL 384-84701-2-3240

W. J. Rousey

OBJECTIVE

The objective of this task is to develop buffer and random access memories with particular emphasis on sterilizability, impact resistance, low-power NDRO operation, and general reliability.

PROGRESS

Phase I of Contract 950986[1] with the Librascope Group of General Precision, Inc., has been completed. The breadboard system shown in Fig. 1 has been delivered and is operating satisfactorily. The breadboard is a 256-word, 16-bit version of the 1024-word, 20-bit engineering model system (Fig. 2 and Table 1) to be completed under phase II of the contract. Phase II was begun in May 1967 and the engineering model is scheduled for delivery in January 1968. The primary purpose of the engineering model is to thoroughly qualify the materials, memory element, and packaging concepts for capsule environments where prelaunch sterilization is a requirement. A milestone chart of this task is shown in Fig. 3.

To this end, an effort parallel to the development of the breadboard system was conducted on the memory element materials and packaging. A memory plane similar to the one used in the breadboard system was subjected to the sterilization requirements of JPL Specification VOL-50503-ETS by the Polymers Research Section at JPL. Figure 4 shows the memory plane prior to sterilization. The encapsulant is RTV 615, a silicone rubber.

Testing Procedure

Procedure of testing was as follows: First, ETO exposure; second, heat sterilization. The memory device was weighed and a color photograph (Fig. 4) taken before exposure; it was again weighed and photographed after ethylene oxide decontamination and heat sterilization (Fig. 5).

(1) Ethylene oxide decontamination:

Composition of decontaminant: 12% ethylene oxide, 88% Freon 12, 35-55% relative humidity.

Time-temperature cycle required by specification: Six cycles of 29 h each with 26 h at 50°C. The actual exposure was six cycles of 36 h each with 28 h at 50°C.

[1]Contract 950986 is for the development of a nondestructive readout (NDRO) data memory unit. The memory is a 1024-word, 20 bits/word random access system using plated wire memory elements. The word wires are woven around the magnetically plated digit wires to form a woven memory plane.

(2) Heat Sterilization:

Composition of sterilant: Dry nitrogen with less than 0.25% oxygen.

Time-temperature cycle required by specification: Six cycles of 76 h each with 64 h at 135°C. The actual exposure was four cycles of 96 h each with 92 h at 135°C.

Total test time: 600 h.

(3) Results: Weights of the memory device were as follows:

	Weight, g	Weight change, g
As received	62.8482	-------
After ETO decontamination	62.9961	+0.1479
After heat sterilization	62.3994[2]	-0.5967

Figure 5 shows the same plane after ETO and heat sterilization. Visual and manual inspection of the memory plane revealed the RTV-615 silicone potting compound to be extremely degraded with essentially no adhesion to the substrate. Degradation of the RTV-615 material was advanced to the point of essentially zero tensile strength and elongation. Comparison of the photographs revealed evidence of adhesion loss at fastener holes in the corners. However, electrical testing revealed no degradation in circuit or component performances and weight loss was nominal.

Analysis of Problems Encountered

Examination of the materials used in the memory device showed that the wrong primer for RTV-615 was used. Primer SS-4120 is recommended by the supplier (General Electric, Silicone Products Dept.), not SS-4101, which was used. Discussion of primers with General Electric brought out the following facts:

(1) Virtually no adhesion of RTV-615 to the substrate could be expected using Primer SS-4101. Primer SS-4120 would give fair adhesion, but a new Primer SS-4155 (not previously available) would provide excellent adhesion.

(2) Use of the wrong primer (SS-4101) would not cause any compatibility problems with RTV-615 that would result in loss of tensile strength and elongation upon exposure to the decontamination and sterilization procedures.

[2] An amount of RTV-615 material estimated to be approximately 0.2 g was lost, so that actual weight was approximately 62.2 g and weight change was approximately -0.4 g.

Consideration of these two facts with other facts available lead to the following possible causes for the observed losses in tensile strength and elongation of RTV-615:

(1) The possibility of errors in the processing of a material, or the possibility of the introduction of contaminants into a material during processing, always exists. Examination of the laboratory processing area and questioning of the laboratory personnel indicated that such possibilities did indeed exist.

(2) The second possible cause was that the ETO decontaminant gas was absorbed into the laminate material of the memory device as well as into the RTV-615 (it is known that the RTV's allow gasses to pass through with relative ease). Then, during the exposure to heat sterilization, the ETO diffused out slowly through the RTV-615 at the relatively high temperature of 135°C, thus causing degradation.

To resolve the problem of loss of adhesion and degradation of tensile strength and elongation, new specimens (where the correct primer and processing methods were used) were exposed to the same sterilization tests. Figure 6 shows the new specimens after sterilization. The sequence of testing was as follows.

After ETO, in an attempt to isolate the possibility of ETO absorption and diffusion in the laminate, half of the RTV-615 slab and one of the dummy units (shown on the left) were placed immediately in heat sterilization. The other half of the RTV-615 slab and the second dummy unit were placed in a 100 to 125°F circulating air oven for several days to desorb ETO decontaminant before placing in heat sterilization.

The significant observations are:

(1) Adhesion of the encapsulant to the printed circuit board is excellent (accomplished by using the correct primer).

(2) No degradation in tensile strength or elongation (microscopic examination revealed no flaws in the exposed boards or castings).

Conclusions

(1) The specimens withstood the ETO and dry heat sterilization successfully.

(2) Absorption and diffusion of the ETO in the laminate (printed circuit board) is not a problem.

(3) The encapsulation process meets the requirements if the procedure is rigidly followed (i.e., the degradation experienced previously was attributed to poor processing techniques).

PLANNED WORK

Similar testing will be conducted during phase II to further validate the above conclusions.

PUBLICATIONS DURING REPORT PERIOD

Contractor Reports

1. Final Report, Phase I, Non-Destructive Readout Data Memory Unit, Contract No. 950986, General Precision, Inc.

ANTICIPATED PUBLICATIONS

None.

Table 1. Summary description of the engineering model memory

1. Capacity	1024 words of 20 bits each, total 20,480 bits
2. Storage means	Magnetic, on a thin-film of permalloy plated on a copper alloy wire substrate
3. Electronics	Integrated circuits and silicon semiconductors
4. Volatility	Nonvolatile
5. Data transfer mode	Bit serial read and write
6. Addressing	Random by word
7. Data transfer rate	0 to 100,000 bit/s
8. Signal interface	Compatible with all common TTL and DTL integrated circuit families
a. Input signals	Clear, address, read or write, data, clock
b. Output signals	Data, bit markers
9. Readout mode	Nondestructive
10. Data alteration	New data is written over the old, no "erase" operation is required
11. Power consumption	40 mW on standby. 240 mW when writing at 100 kHz clock rate
12. Power supply tolerance	$\pm$ 10%
13. Weight	4 lb
14. Volume	48 in^3

Fig. 1. NDRO breadboard memory system

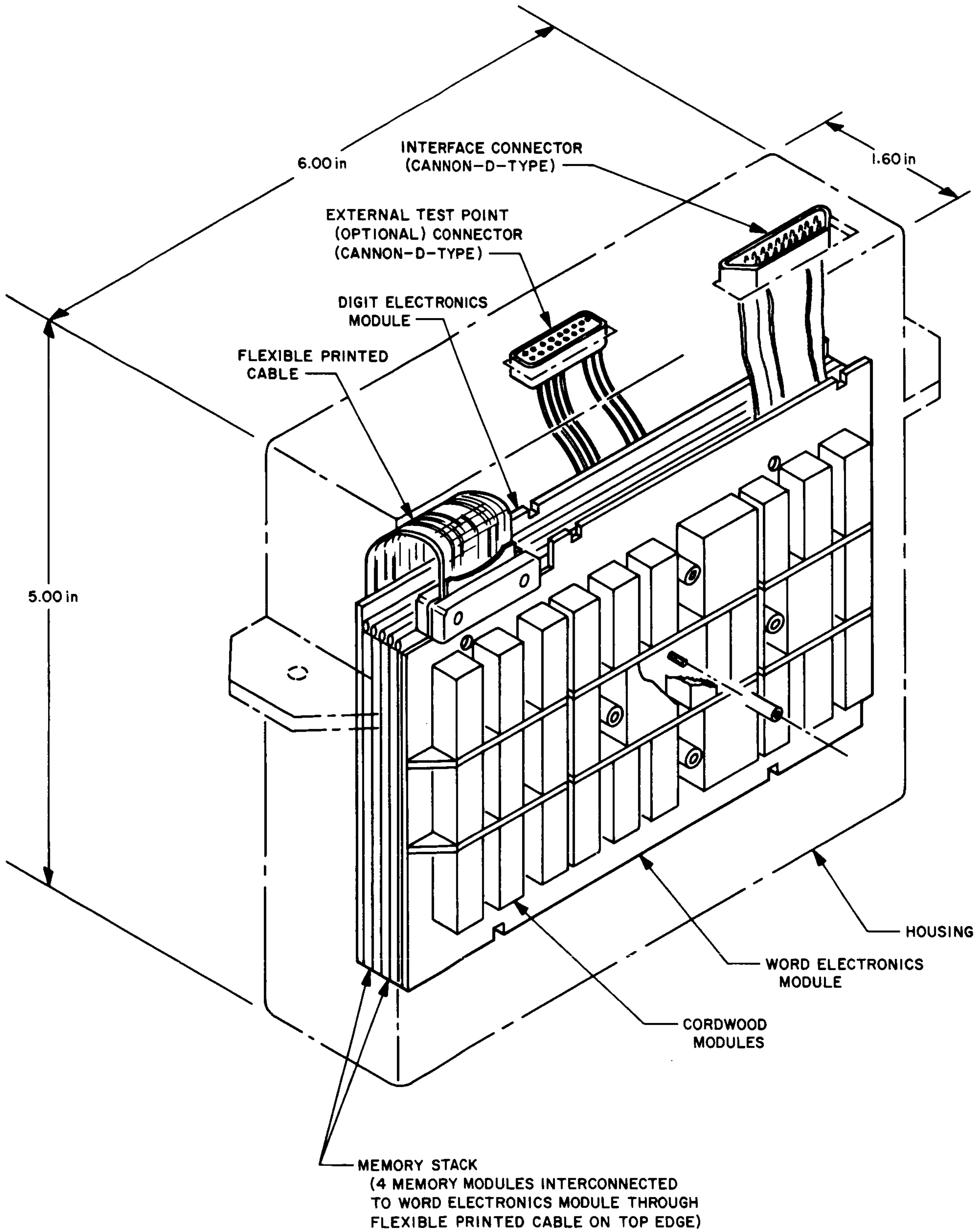

Fig. 2. Engineering model memory system package

MAJOR MILESTONES	PRIOR FY				PRESENT FISCAL YEAR												NEXT FY			
	QUARTER				MONTH												QUARTER			
	1	2	3	4	J	A	S	O	N	D	J	F	M	A	M	J	1	2	3	4
1. DELIVERY BREADBOARD (CONTRACT 950986)		▽																		
2. BREADBOARD TESTING		▭	▭	▭	▭	▭	▭	▭	▭	▭	▭									
3. BREADBOARD REPORT					▽															
4. ENGINEERING MODEL FABRICATION																				
(CONTRACT 950986-PHASE II)				▭	▭	▭	▭	▭	▭	▭										
5. ENGINEERING MODEL DELIVERY											▽									
6. ENGINEERING MODEL FINAL REPORT												▽								
7. ENGINEERING MODEL TESTING												▭	▭	▭						

Fig. 3. Milestone chart for sterilizable science data buffer

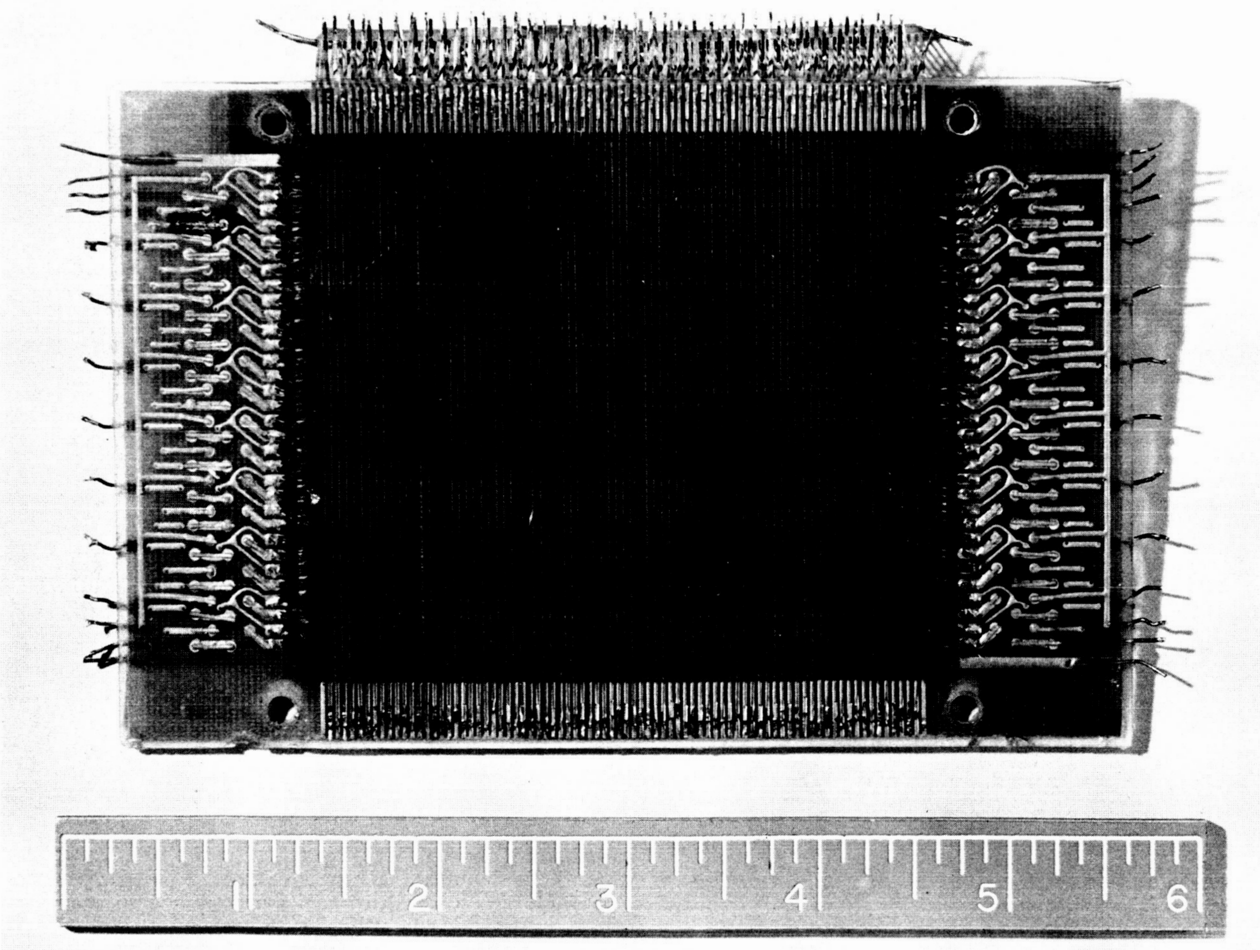

Fig. 4. Memory plane (before sterilization)

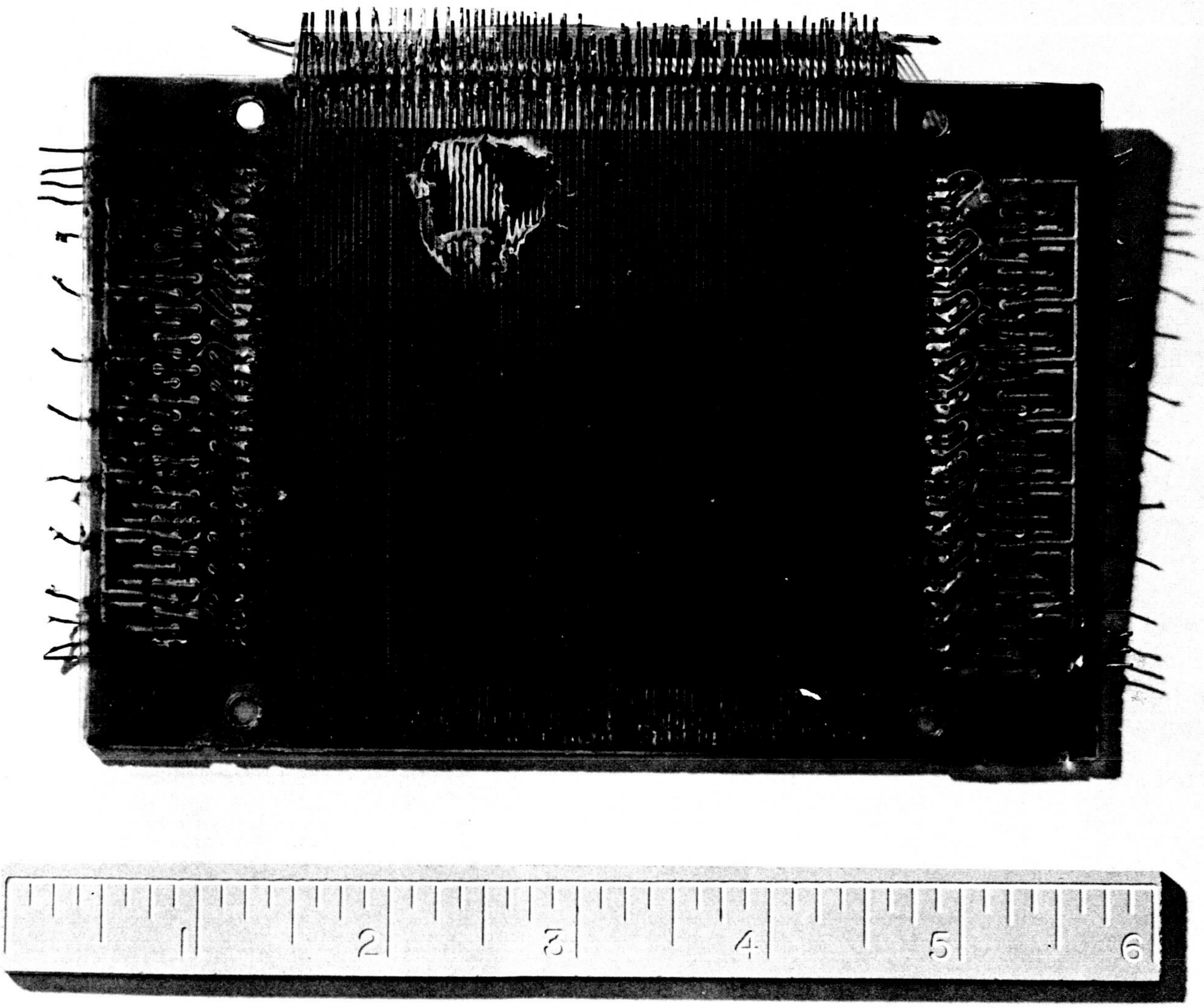

Fig. 5. Memory plane (after sterilization)

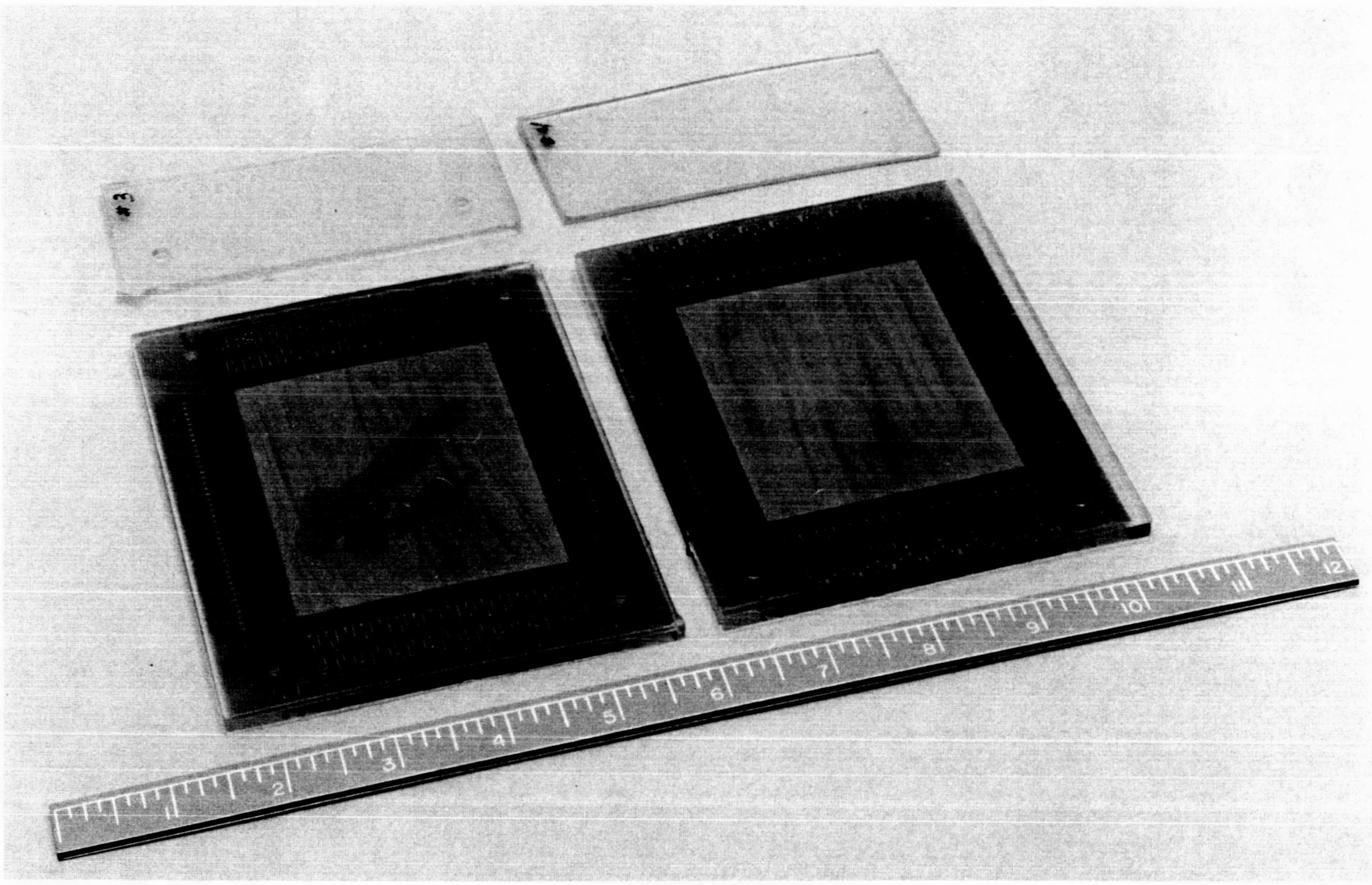

Fig. 6. Dummy memory samples (after sterilization)

MINIATURE ELECTRO-OPTICAL IMAGE DETECTOR STERILIZATION

NASA Work Unit 186-58-06-03-55
JPL 384-84301-2-3230

L. R. Baker

OBJECTIVE

The present technology relating to vidicons for space imaging system application has not made available vidicons capable of meeting present sterilization requirements. Additionally, it is logical to assume that any sterilizable component would find application in a high-impact environment. Therefore, the purpose of the program is to design, fabricate, and test a vidicon-type image sensor capable of surviving dry heat sterilization and ETO decontamination. The tube elements and structure are being designed to withstand a 3000-g shock, since a sterilizable component will logically find application in a high-impact environment. (The ruggedization aspects are being funded by a companion OART Work Unit 125-24-01-05-55.)

Phase A of the program was logically divided into two phases to run concurrently. Task I was the development of the sterilizable photoconductor, and task II was the development of the complete ceramic vidicon incorporating the sterilizable photoconductor. Phase B is a continuation of task II to improve the design and reliability of the vidicon.

PROGRESS DURING REPORTING PERIOD

Work on the phase B program progressed well until recently, when problems in the tube fabrication caused the schedule to slip. However, at least six operable vidicons have been made, one of which will be delivered to JPL at the end of June to support work in a companion program, "Ruggedized Imaging System Development" (NASA Work Unit 125-24-01-05).

The problems which have been encountered are all related to the electron gun structure. Some of the ceramic parts were defective when they were received from the vendor in that they had hairline cracks. Four tubes were lost in fabrication because of these cracks. In the gun, the heater tends to move from its cup during the 3000-g shock, and attempts to constrain the heater have not been too successful. However, using alumina powder and a Sauereisen cement plug looks very promising to improve the heater reliability. The G_1/G_2 ceramic spacer has cracked in the brazing process on some of the recent tubes. The problem was caused by thermal stress because of decreased brazing material that was a fix to solve the G_1/G_2 high-resistance short problem. A molybdenum plate will be brazed to the bottom of G_1 and G_2 cups to achieve a much better thermal expansion match between the cups and the ceramic spacer. The schedule is shown in Fig. 1. At the end of phase B, two vidicons will be delivered. Present indications are that even though the program will run late, the cost is not expected to overrun.

FUTURE PLANS

The phase C proposal has been received from RCA, and the schedule is shown in Fig. 2. The desired program for phase C is to improve the margin of safety of

the mesh and the heater to survive the high-g shock, to improve the image quality of the tube, and to deliver six tubes, three of which shall have successfully passed the entire qualification test as shown in Fig. 3.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

"Interim Results of the Development of a Sterilizable, Ruggedized Vidicon," SPS 37-43 Vol. IV.

ANTICIPATED PUBLICATIONS

Contractor Reports and Papers

1. Phase B Interim Reports.

2. Paper to IEEE Electron Devices Conference in October (presented by RCA).

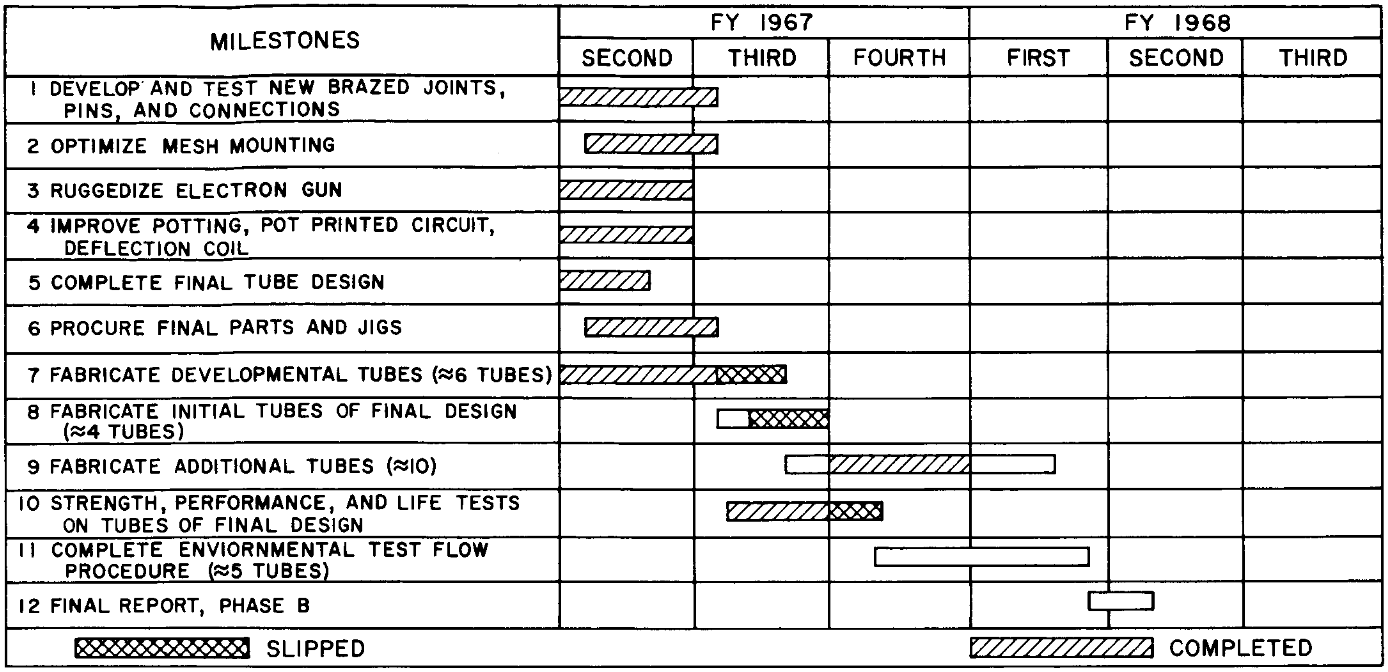

Fig. 1. Phase B ceramic vidicon development

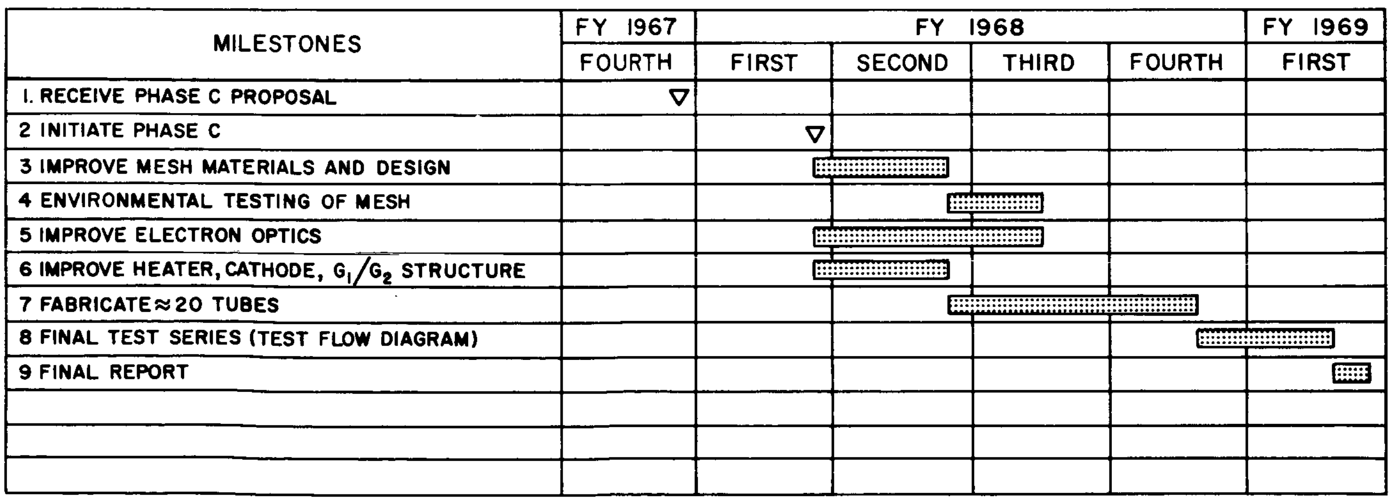

Fig. 2. Phase C ceramic vidicon development

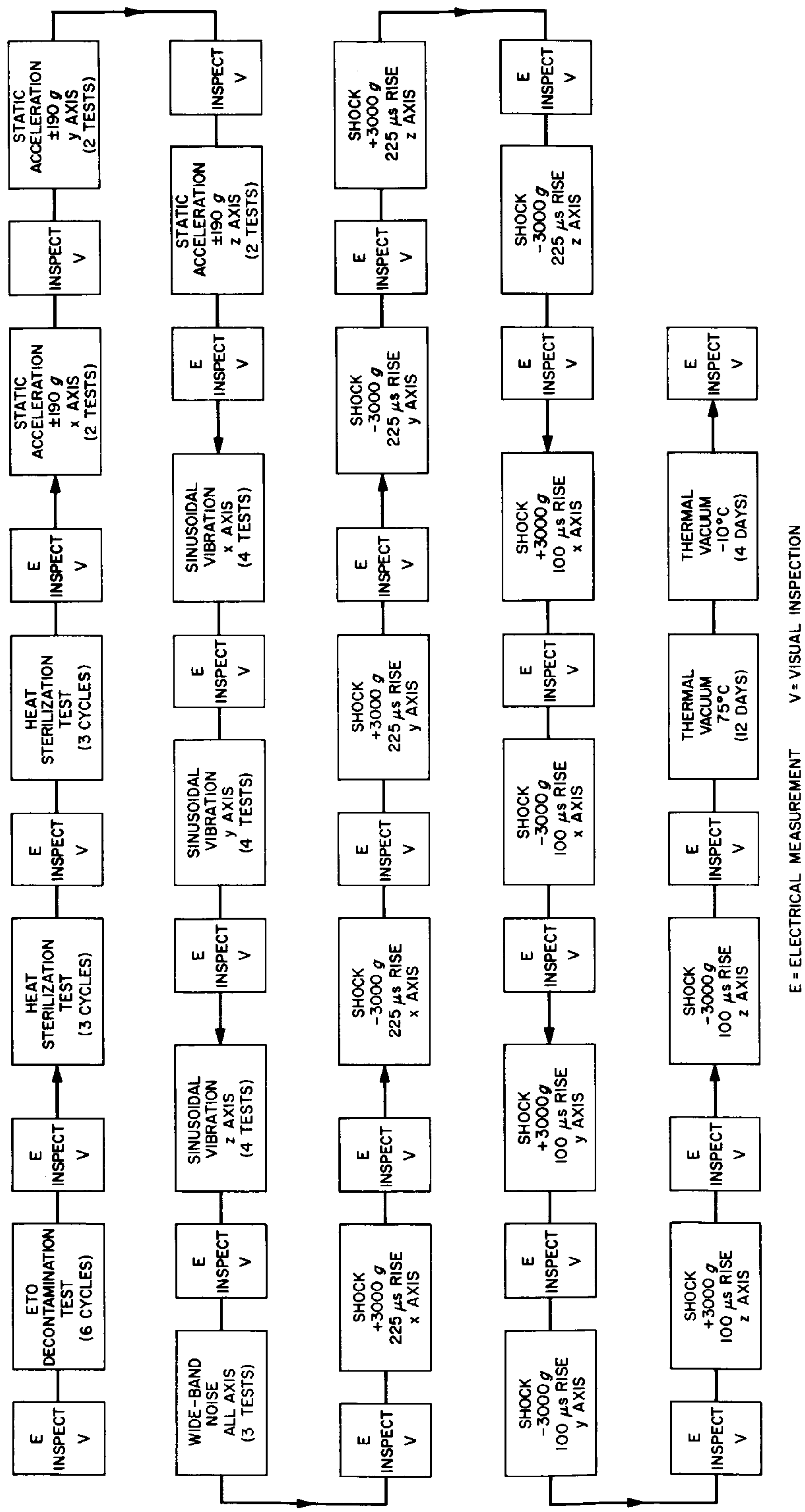

Fig. 3. Test flow diagram

REED-CAPACITOR-MODULATOR STERILIZATION

NASA Work Unit 186-58-06-04-55
JPL 384-84401-2-3220
J. R. Locke

OBJECTIVE

The primary objective of this task is to develop a miniaturized modulator capable of converting low-level direct current (as low as 10^{-15}A) into a proportional sinusoidal voltage. The more recent immediate goal has been to find an organization that could complete the work started under an earlier JPL contract (Contract 950668). This new contract would specifically be directed at verifying (and improving if necessary) the production technology developed earlier, substantiating the ability of the device to survive sterilization, and establishing an organization capable of building the reed-capacitor modulator for our future needs.

STATUS REPORT

A survey information request (SIR 2199) was conducted to determine the capabilities and interests of thirty-two companies that were known to either possess personnel or equipment necessary to do the job or manufacture transducers similar to the reed-capacitor modulator. Only three organizations indicated a desire to be considered. These three companies were sent requests for proposals, and two declined to bid. The third company, Cary Instruments, submitted a counterproposal which was unsatisfactory. Upon our request, Cary submitted a second proposal addressed to our original requirements. Their proposed cost was 2-1/2 times greater than our estimate, and the development time was quoted at 2-1/3 yr on a best-effort basis. Another objectionable aspect of their proposal was data restrictions. Cary felt that the existing design required modification in which they would have to use their own proprietary techniques.

The reed capacitor is a demonstrated technique of measuring very low currents where the only alternatives are the use of the electron multiplier or the electrometer tube. The electrometer tube has the disadvantages of high filament power and large dc temporal drift. The electron multiplier requires a very tightly regulated high-voltage supply and is limited to applications utilizing electron ballistics. In contrast, the miniaturized reed capacitor is a very rugged, low-power, small (compared with the electron multiplier), low-drift device. However, the disadvantage of the capacitor is its relative long response time. Because fast scan times are required for both the atmospheric mass spectrometer and the combined gas chromatograph-mass spectrometer, future application of the reed capacitor is questionable. For this reason, in conjunction with the unfavorable industry response, it has been recommended that this task should be discontinued for now.

FUTURE ACTIVITIES

During the fourth quarter of FY 1968, the reed-capacitor modulator task will be reviewed to determine if future applications have developed and/or if the climate of industry is more favorable.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

SENSOR STERILIZATION AND TEST PROGRAM
NASA Work Unit 186-58-06-06-55
JPL 384-84601-2-3220
R. A. Wengert

OBJECTIVE

The purposes of this program are (1) the development of sterilizable, ruggedized, and highly reliable sensors which are unique to scientific instrumentation and, (2) following the development, subject the sensors to an evaluation program which will prove them worthy for use during planetary entry and landing missions. The sensors being studied are (1) GM counter tubes, (2) inorganic scintillation crystals, (3) photomultiplier tubes, (4) solid-state radiation detectors, and (5) an optical detector-scintillation crystal assembly. A kryptonated copper sensor (for the measurement of oxygen) and an aluminum oxide sensor (for the measurement of water vapor) will also be evaluated.

GEIGER-MULLER COUNTER TUBES

All development effort has been completed. The development models and an additional quantity of purchased tubes, manufactured to the same specifications, are being evaluated in the test portion of this program.

SOLID-STATE RADIATION DETECTORS

Plans for further development have been tabled for the present, pending the results of additional testing in the laboratory. Tests to date have raised doubt as to the need for continued development. Technical Measurement Corporation, the original development contractor, has discontinued producing diffused detectors. Another organization, Nuclear Equipment Corporation, has been formed to produce this and other detector types and includes on its staff the principal investigator and others who worked on the original development. Another firm, Molechem, Inc., has introduced a multidiffused detector claiming comparable operating characteristics and a 150°C storage temperature capability. Testing will be performed on detectors from both sources. Additional development will be proposed only if negative results are obtained.

INORGANIC SCINTILLATION CRYSTALS

The crystal packages have successfully survived the sterilization and high-level shock tests. They are now being subjected to the remaining environmental tests. The development effort will be completed and the final report received early in the first quarter of FY 1968.

PHOTOMULTIPLIER TUBES

The contractor is attempting to reduce the resistivity of the photocathode and the change in the operating characteristics experienced as a result of heat sterilization. Two series of tests have been conducted thus far: the deposition of the

photocathode surface on conductive substrates of chromium and aluminum. Although the resistivity problem does seem to have been solved, the behavior of the operating characteristics remain unstable and unpredictable. The contractor, during an in-house effort, has developed a new photocathode with much better initial characteristics . To date, no test results have been obtained on the behavior following sterilization. A redirection of effort, proposed by the investigators, is being evaluated at the present time.

OPTICAL DETECTOR-SCINTILLATION CRYSTAL ASSEMBLY

The breadboard system has been tested with negative results to this time. The theoretical calculations and detector sensitivity measurements are being reevaluated in an effort to determine and correct the cause of failure.

ALUMINUM OXIDE SENSOR

The purchase of the aluminum oxide detectors and the necessary instrumentation for detector evaluation has been initiated. The fabrication of the test fixture has been started.

TEST AND EVALUATION PROGRAM

The evaluation of GM counter tubes is continuing. A printer has been obtained, and testing is being performed in a semiautomatic mode. Switching logic is being designed, and when completed the test station will be automated. All tubes were subjected to one sterilization cycle (36 h at 145° C) in December 1966 and have been undergoing operational evaluation since that time. The distribution of relative plateau slope determinations of two thin side wall tubes (type 5112R) is shown in Figs. 1 and 2 and that of three mica-end window tubes (type 6226) in Figs. 3-5. A summary of test data is presented in Table 1. When the test station has been placed in the automatic mode of operation, similar data will be obtained for all tubes.

All solid-state radiation detectors were also subjected to one sterilization cycle in December 1966. The test station is in automatic operation, and evaluation of the detectors may continue uninterrupted. The distribution of determinations of one of the operating characteristics--energy resolution--of four of the detectors is shown in Figs. 6-9. The test data is summarized in Table 2. Similar tests will be conducted on the balance of the detectors obtained as the result of the basic development contract and on those being purchased from Molechem, Inc., and Nuclear Equipment Corporation. A milestone chart indicating the schedule established for this work unit is shown in Fig. 10.

PUBLICATIONS DURING REPORT PERIOD

Contractor Reports

1. Dumas, E. J., Improved Sterilizable Multiplier Phototubes, Electro-Mechanical Research, Inc., Second Quarterly Progress Report, January 10, 1967 (JPL Contract 951555).

2. Dumas, E. J., Improved Sterilizable Multiplier Phototubes, Electro-Mechanical Research, Inc., Third Quarterly Progress Report, April 12, 1967 (JPL Contract 951555).

ANTICIPATED PUBLICATIONS

Contractor Reports

1. Dumas, E. J., Improved Sterilizable Multiplier Phototubes, Electro-Mechanical Research, Inc., Fourth Quarterly Progress Report, July 1967 (JPL Contract 951555).

2. Ruderman, W., Sterilizable Inorganic Scintillation Crystals, Isomet Corp., Final Report, July 1967 (JPL Contract 950768).

3. Ruderman, W., Sterilizable Optical Detector-Scintillation Crystal Assembly, Isomet Corp., Final Report, August 1967 (JPL Contract 950982).

Table 1. Test data summary of GM counter tubes

Detector type	S/N	Determinations	Relative plateau slope, %/100 V	
			Mean	Median
Thin side wall	4125	134	7.1	7.0
	4196	136	6.7	6.8
Mica end window	3142	107	4.0	4.0
	3165	183	2.3	2.1
	3455	133	1.5	1.4

Table 2. Test data summary of solid state radiation detectors

S/N	Active area, cm^2	Determinations	Energy resolution keV (FWHM)	
			Mean	Median
4	0.5	285	57	57
9	0.5	132	75	75
11	2.0	263	57	56
20	3.0	153	71	70

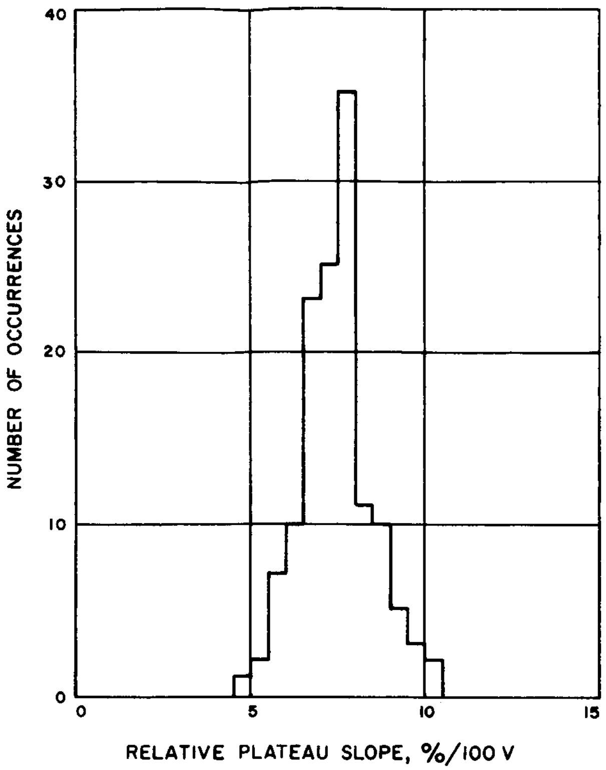

Fig. 1. Number of occurrences vs relative plateau slope, type 5112R, S/N 4125

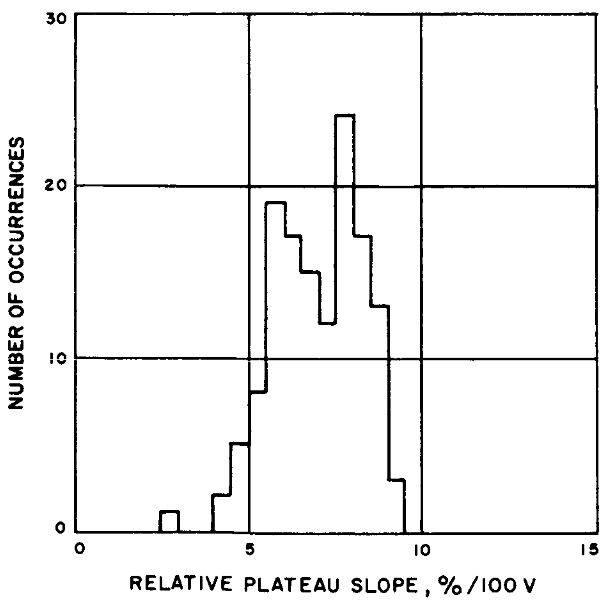

Fig. 2. Number of occurrences vs relative plateau slope, type 5112R, S/N 4196

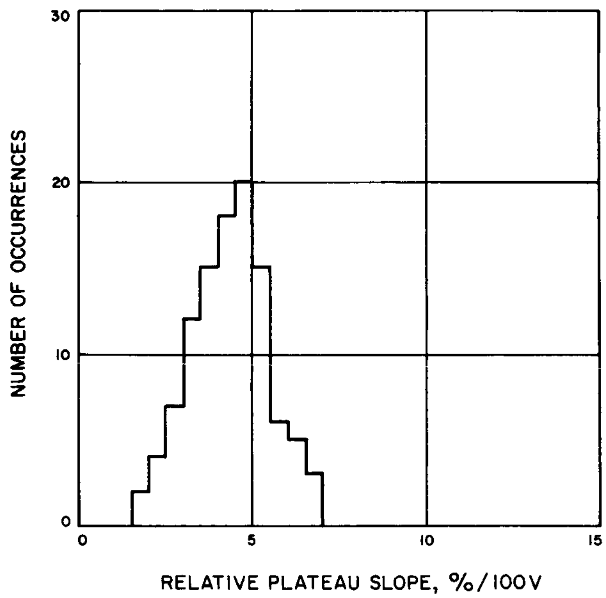

Fig. 3. Number of occurences vs relative plateau slope, type 6226, S/N 3165

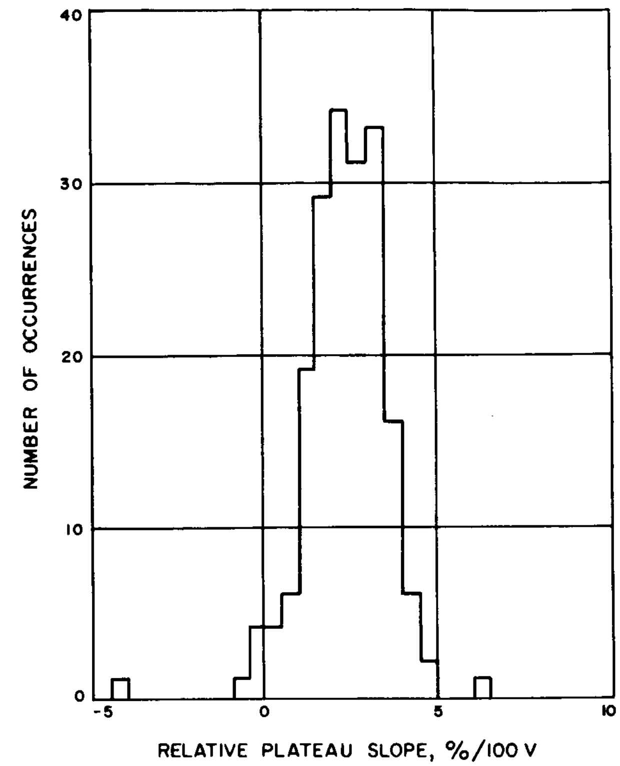

Fig. 4. Number of occurrences vs relative plateau slope, type 6226, S/N 3165

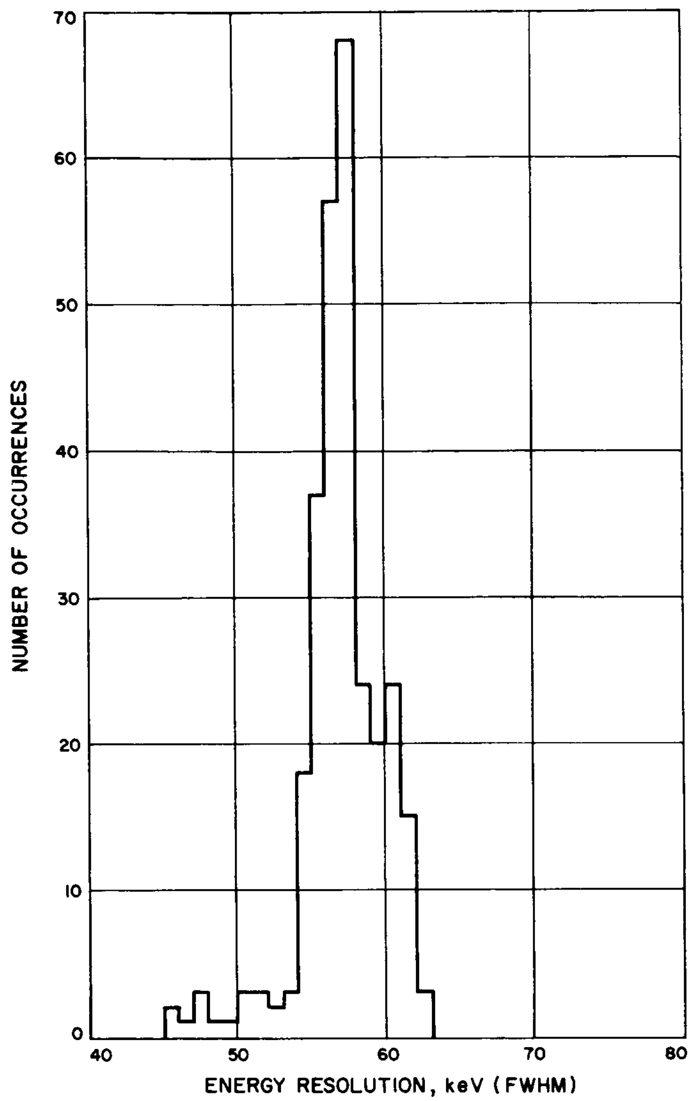

Fig. 6. Number of occurrences vs energy resolution, S/N 4

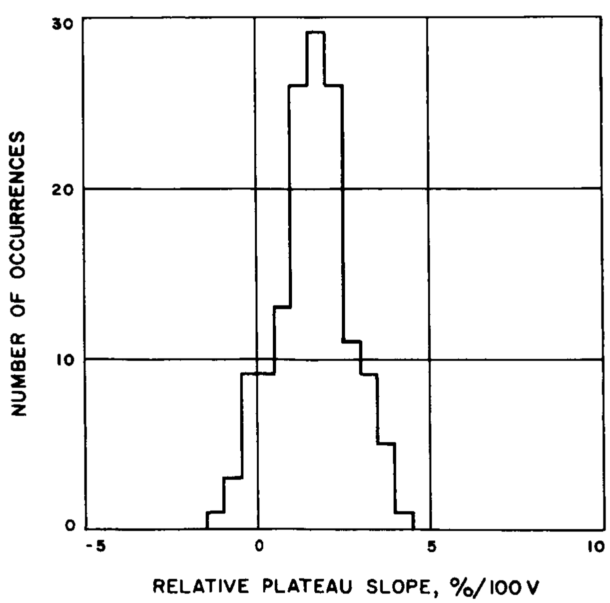

Fig. 5. Number of occurrences vs relative plateau slope, type 6226, S/N 3455

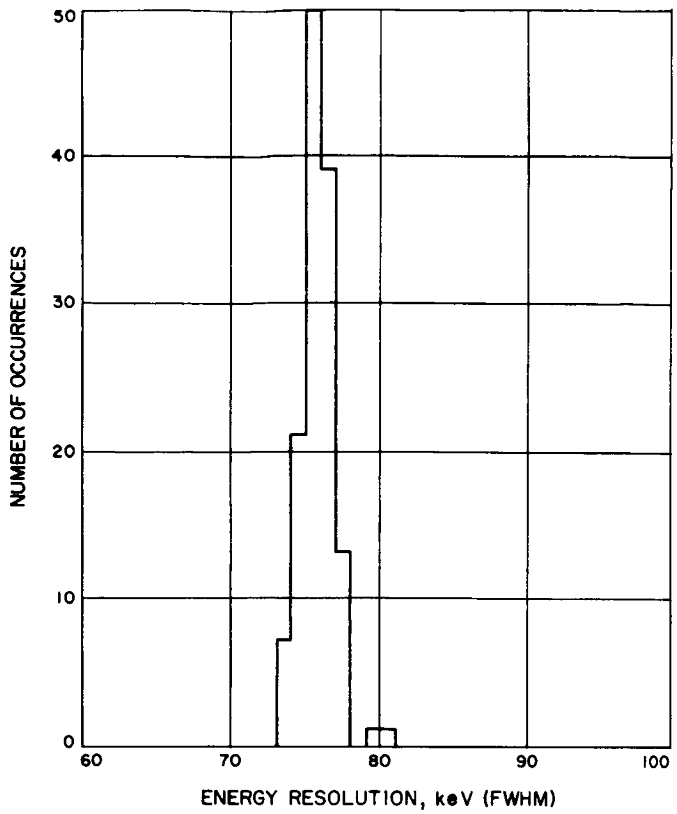

Fig. 7. Number of occurrences vs energy resolution, S/N 9

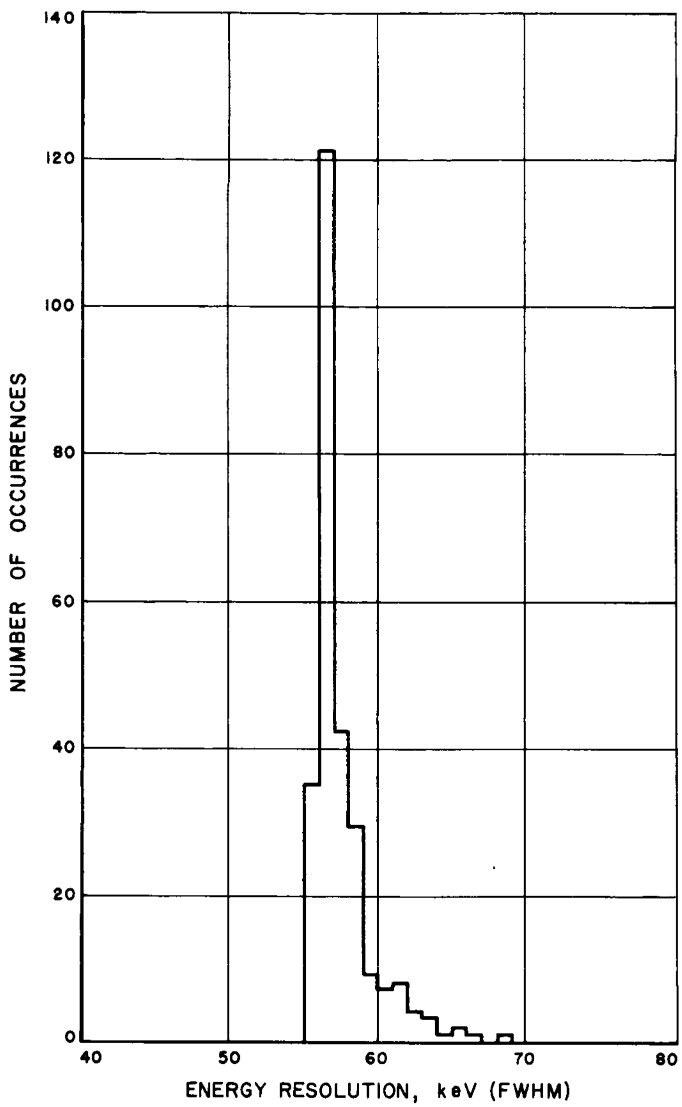

Fig. 8. Number of occurrences vs energy resolution, S/N 11

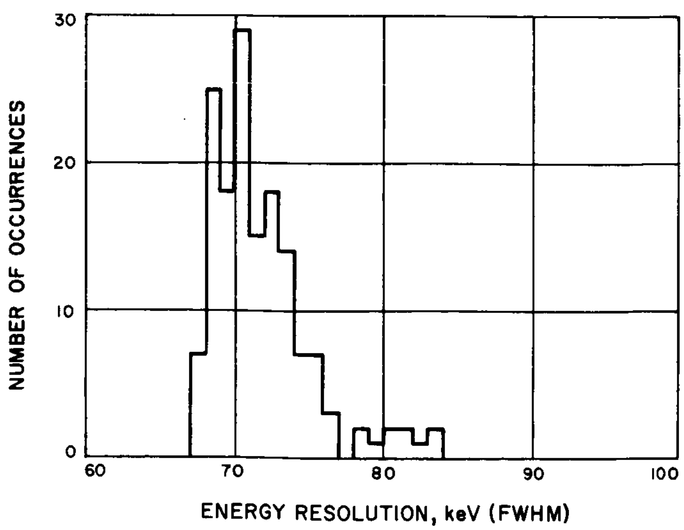

Fig. 9. Number of occurrences vs energy resolution, S/N 20

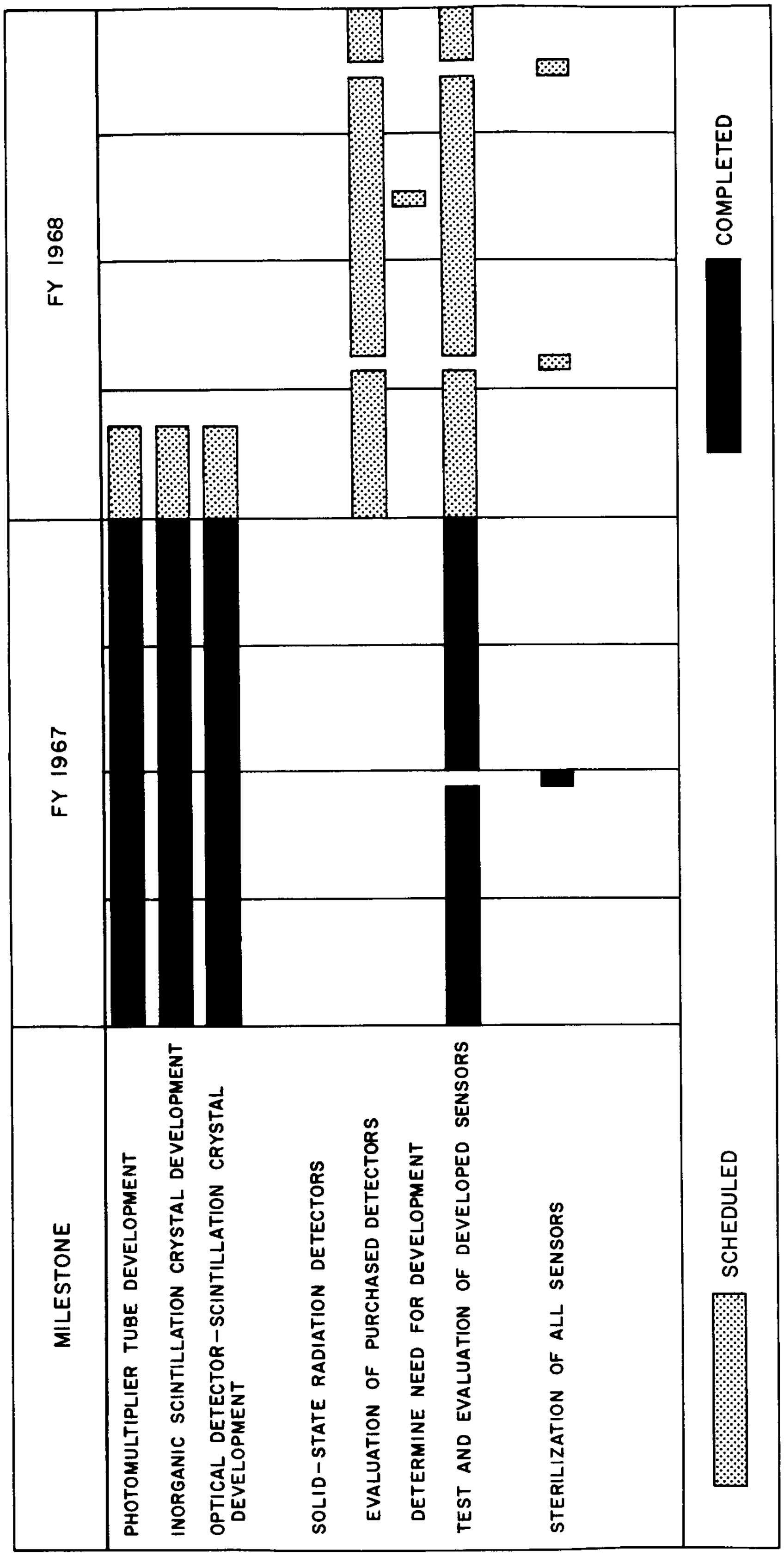

Fig. 10. Milestone chart for sensor sterilization and test program

STERILIZABLE SOLID ROCKET DEVELOPMENT

NASA Work Unit 186-58-08-01-55
JPL 384-81901-2-3810

J. Shafer

OBJECTIVE

The objective of this task is to demonstrate feasibility and solve the engineering problems involved in using solid propellant rocket motors for those planetary exploration spacecraft that will have to be sterilized to assure planetary quarantine.

CSAD EFFORT

A Capsule System Advanced Development (CSAD) program was recently initiated at this Laboratory in an effort:

(1) To develop experience in several critical and new technologies related to planetary entry and landing.

(2) To develop an understanding of the sybsystems such that realistic performance estimates can be made.

Its major objective is the design, development, and fabrication of an entry system (including most, though not necessarily all, subsystems) which will be subjected to a series of functional tests, to the heat sterilization cycle, and to selected environmental tests. One of the obvious benefits will be the orientation of appropriate R&D efforts toward the solution of real project problems in future entry programs. Propulsion Division representation for design and coordination purposes and for support (i.e., sterilizable pyrotechnic operations and the sterilizable deflection motor) is being funded under this task. The results from the 2-lb motor work (discussed below) are being applied to the CSAD Task.

PROPELLANT DEVELOPMENT

Because of the favorable properties at sterilization temperatures, emphasis continues on the evaluation and use of saturethane propellants (i.e., formulations based on saturated, hydroxyl-terminated polybutadiene crosslinked with isocyanate into a polyurethane network). Confirmation of their marked superiority over the best polybutadiene acrylic acid (PBAA) type of propellant evaluated to date at JPL was established in direct comparison tests with 2-lb motors using a tubular configuration that was case-bonded throughout its lateral surface. See Table 1.

Further evaluation of the saturethane propellants has revealed (1) that their low-temperature properties resemble those of the polyurethanes based on polyether prepolymers (e.g., JPL 540) and (2) that prepolymer lot-to-lot variations in propellant curing rates are larger than desired. A study now under way promises to reduce the variation by establishing better quality control specifications and process procedures.

During the last 6 mo development of an aluminum analog of the nonmetallized saturethane propellant has been initiated so that a higher performance, sterilizable propellant would be available if the present constraint of "solids-free exhaust products from the motor" were to be relaxed. Then several potential applications, such as the Voyager de-orbit motor, would benefit significantly by a reduction in motor weight and increase in payload capability.

MOTOR DEVELOPMENT

Two unlined 50-lb SYNCOM motors (see the larger motor in Fig. 1) failed during their second sterilization cycle owing to propellant-steel incompatibility at 275°F which destroys the propellant-to-case bond. Considering the failure mechanism, it is significant that the propellant survived the first cycle in excellent condition in a high-performance configuration (i.e., a completely case-bonded charge with a web fraction of 0.667).

In separate experiments with 2-lb motors (see Fig. 1) the incompatibility was eliminated by utilizing a liner-insulation with a suitable filler as a protective inter-layer. This concept will be extended to future sterilization tests with the larger 50-lb motor as quickly as practicable.

The feasibility of heat-sterilized, case-bonded motors in the 2-lb size has now been demonstrated. Three lined and fully case-bonded motors with web fraction of 0.5, 0.667, and 0.75 were successfully fired after six 56-h cycles at 275°F. Figure 2 shows the pressure-time curve for the sterilized motor of 0.5 web fraction and an identical unsterilized control motor. The characteristic exhaust velocities C* of the two agreed within the accuracy of the instrumentation, indicating very small, if any, change in ballistics from the sterilization treatment.

ADIABATIC SELF-HEATING

The work on the contract with the Naval Ordnance Test Station on adiabatic self heating (Purchase Order Z351290) has shown that:

(1) A 50-lb SYNCOM motor, which utilized a PBAA propellant, ignited spontaneously after exposure to a temperature of 325°F for a period of 72.4 h--in good agreement for this type test with a predicted time of 65 h.

(2) Motors of the SYNCOM geometry up to 30 in. diam with PBAA propellant will not cookoff at 275°F.

A $30,000 supplement to the indicated purchase order has been issued in order to carry out kinetic studies and adiabatic self-heating tests with saturethane propellants and motors.

PARTICIPATION IN SYMPOSIA OR MEETINGS

Status reports on the sterilization efforts at JPL were presented at:

(1) CPIA Propellant Binder Symposium at Aerojet-General Corporation, Sacramento, California on March 9 - 10, 1967.

(2) 2nd ICRPG/AIAA Solid Propulsion Conference at Anaheim, California on June 8, 1967 (Specialist Meeting on Heat Sterilized Motor Technology).

During the last 6 mo a meeting was held with General Tire and Rubber Company on the problems of tailoring saturethane prepolymers. Discussions were also held with Langley Research Center personnel on the sterilization work as applied to the Voyager Project.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

Table 1. Comparison of heat sterilization resistance of PBAA and saturethane propellants in 2-lb flight motors (charge configuration: tubular, case-bonded throughout)

Charge web fraction	Number of successful 56-h sterilization cycles at 275°F without charge failure	
	PBAA	Saturethane
0.667	3	6[a]
0.75	0	6[a]
0.80	0	6[a]

[a]Tests stopped after 6 successful cycles.

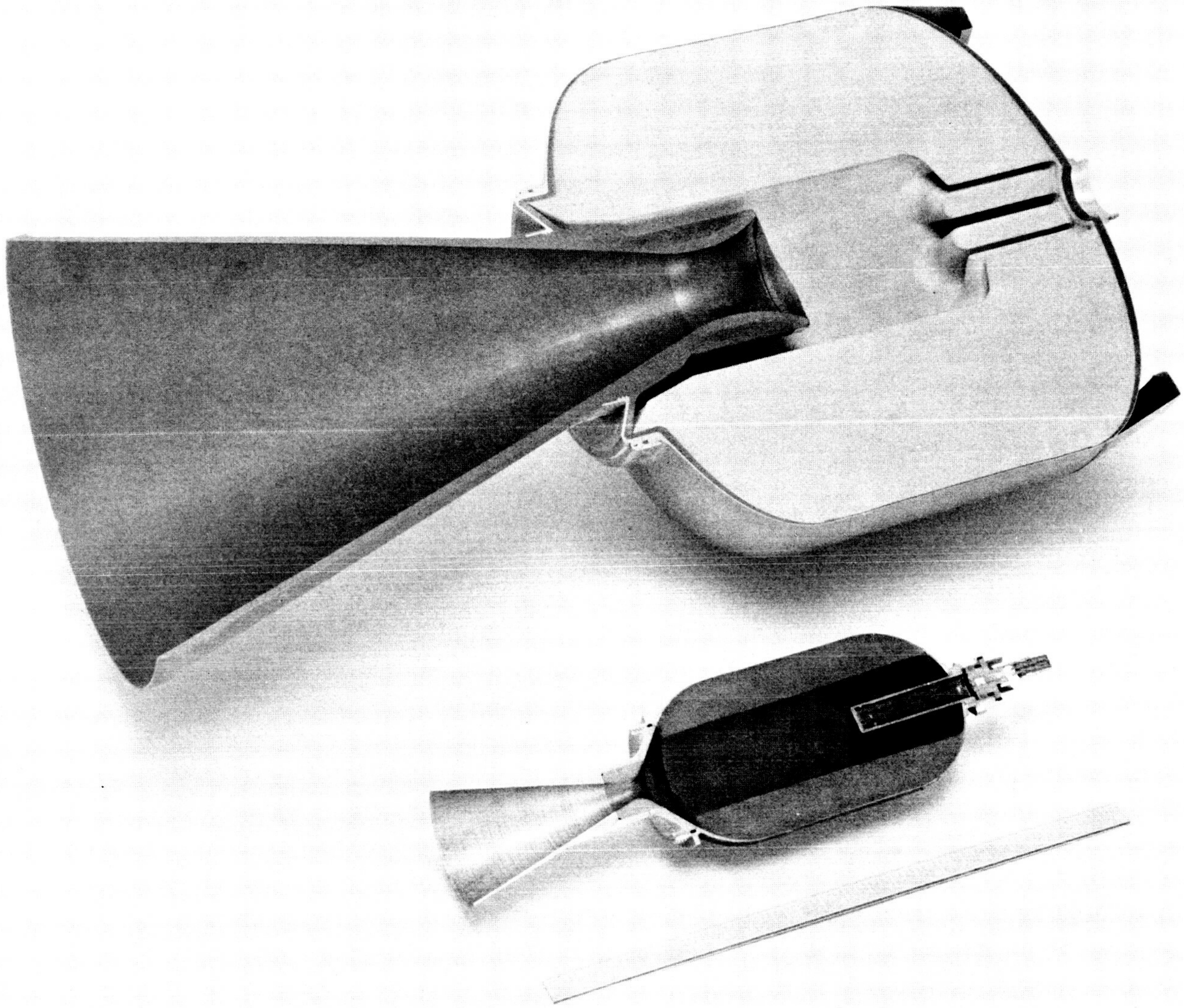

Fig. 1. Motors used in sterilization tests

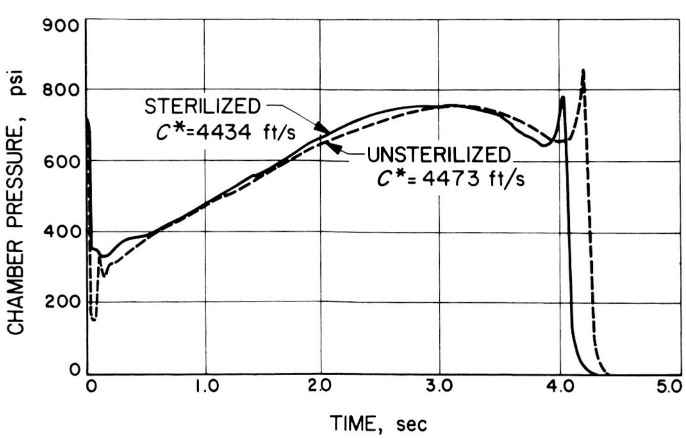

Fig. 2. Pressure-vs-time curves for sterilized and unsterilized 2-lb motors using saturethane propellant

STERILIZABLE LIQUID PROPULSION SYSTEM DEVELOPMENT

NASA Work Unit 186-58-08-02-55
JPL 384-82101-2-3840

M. E. Guenther

OBJECTIVE

The objective of this work unit is to develop the technology required for the use of sealed, ethylene-oxide-compatible, heat-sterilizable liquid propulsion systems. Such systems will be required for probes or capsules that enter planetary atmospheres. The liquid supply system technology will also have application as a monopropellant supply system for a turboalternator auxiliary power unit driven by gaseous products from hydrazine decomposition.

STATUS OF WORK UNIT

This work is being handled primarily by an industry contractor. The contractor is conducting a design and experimental investigation, and will perform a feasibility demonstration of a sterilizable liquid bipropellant propulsion system. To conduct this program, the contractor designed an integrated, modular bipropellant system, and initiated the procurement of the required component parts. The pretesting of these parts to determine their compatibility with heat cycling is progressing and will be followed by the assembly of the component parts into a complete system, followed by both ethylene oxide exposure and thermal cycling. Finally, a demonstration firing of the sterilized system will be conducted with the system examined for possible adverse effects.

During this report period the contractor has progressed to the point in the compatibility testing that stainless steels are found to be unacceptable with N_2O_4 at 275°F. Titanium is the only completely satisfactory metal with N_2O_4 (inhibited) at 275°F. No problems have been experienced between most candidate metals and materials with MMH at 275°F when proper cleaning and passivation techniques are utilized.

Additional efforts in the areas of larger scale systems and more comprehensive compatibility testing are to be initiated during FY 1968.

A secondary (backup) effort is being initiated in-house for FY 1968. This in-house effort will be in the form of a prototype monopropellant system capable of withstanding the sterilization environment without appreciable degradation of performance when test-fired. A simple breadboard monopropellant system has been subjected to the sterilization heat cycle and test-fired successfully during this period. The FY 1968 prototype system will be designed, fabricated, assembled, and tested. This system will utilize existing in-house developed components and technological information gained from the Martin-Denver contract as well as in-house information.

PUBLICATIONS DURING REPORT PERIOD

Contractor Reports

1. Two quarterly reports.

ANTICIPATED PUBLICATIONS

JPL SPS Contributions

1. Evans, D., and Guenther, M. E., "Sterilizable Liquid Propulsion System," SPS 37-47, Vol. IV.

ESTABLISH AN APPROVED LIST OF HEAT STERILIZABLE ELECTRONIC COMPONENT PARTS

NASA Work Unit 186-58-13-01-55*

JPL 544-3BG50-1-3540

J. Visser

OBJECTIVE

The objective of this task is to support the NASA thermal sterilization policy by studying the effects of the thermal sterilization environment on the reliability of electronic piece parts during long life. The study will result in the establishment of a list of electronic piece parts capable of operating reliably for a minimum of 10, 000 h after being subjected to heat sterilization.

PROGRESS OF INDIVIDUAL TEST PROGRAMS

The following paragraphs describe the progress of each separate task. A test status summary sheet is shown in Fig. 1.

1. ZPP-2101, Capacitor Test Extension (Preston Scientific)

This program has been completed except for release of the JPL final report. A rough draft of the JPL final report has been sent to the Technical Information and Documentation Division for release by July 1967. The 6, 000-h life test extension revealed no statistically significant catastrophic degradation effects due to heat sterilization, although one type of solid tantalum capacitor and the glass-type capacitor apparently reached a wearout stage as there were increasing catastrophic failures after 11, 000 h.

2. ZPP-2108-GEN, Capacitor Test Phase II (Mid-Continent)

The contract has been executed. The contractor's test procedure is being approved by JPL. Phase II includes 19 capacitor types that were selected using the results of the original test ZPP-2101-GEN and anticipated future usage. The test program is scheduled to be completed by April 1969. The contractor's test procedure has been approved by JPL. Initial screening and burn-in have been completed. Postscreening measurements are scheduled to be completed by July 7, 1967.

3. ZPP-2102-GEN, Fixed Resistor 6, 000-h Extension (Preston Scientific)

The 6, 000-h extension has been completed. None of the resistors evidenced wearout, and there was only one catastrophic failure. The parameter drift trend established during the 10, 000-h phase of the test program continued during the additional 6, 000 h without significant change. The 6, 000-h extension final report is available as a JPL internal document.

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*Funded in FY 1967 by Voyager Project.

4. ZPP-2112-GEN, Fixed Resistor Test - Phase II (Mid-Continent)

The test contract has been executed. Postscreening measurements, temperature coefficient measurements, and postheat sterilization measurements have been completed. The program is scheduled to be completed by September 1968. To date there has been insufficient information available to form any conclusions.

Add-on Test

The contract modification to add ten new part types to the test program has been executed. Initial screening measurements are scheduled to begin on July 11, 1967.

5. ZPP-2109-GEN, Trimming Resistor Test - Phase II (Mid-Continent)

The test contract has been executed. Postscreening measurements and wiper noise have been completed. Heat sterilization testing is in progress and the post-sterilization measurements are scheduled to be completed by July 5, 1967. The program is scheduled to be completed by September 1968. To date there has been insufficient information available to form any conclusions.

Add-on Test

The contract modification to add four new part types to the test program has been executed. Initial screening measurements are scheduled to begin on July 13, 1967.

6. ZPP-2103, Trimming Resistor Test (Boeing Aircraft)

The test program has been completed. There were no statistically significant catastrophic effects caused by heat sterilization, although there was evidence of parametric drift during life testing. The JPL final report has been forwarded to the Technical Information and Documentation Division, and it is scheduled to be released by August 31, 1967.

7. ZPP-2104-GEN, General Diode Test (Boeing Co.)

The 6,000-h measurements have been completed, and they have been returned to life-testing. The only significant catastrophic degradation was with the gallium arsenide type. As this is an 85°C rated part, it was not expected to withstand heat sterilization, although we now have proof.

Add-on Test

The contract modification to add nine new part types to the test program has been executed. Initial screening measurements are in progress and they are scheduled to be completed by July 5, 1967. Completion of testing is scheduled for March 1968. There has been insufficient information available to form any conclusions.

8. ZPP-2106-GEN, Varactor Test - Phase II (Microwave Assoc.)

The contract has been executed. Initial screening measurements are scheduled to begin on July 6, 1967. Completion of testing is scheduled for July 1969.

9. ZPP-2105-GEN, Varactor Diode Test (Microwave Assoc.)

The JPL final report has been submitted to the Technical Information and Documentation Division. The report is scheduled to be released by July 7, 1967. There were no statistically significant catastrophic failures due to heat sterilization effects, although there has been evidence of parametric drifting during life testing.

10. ZPP-2106-GEN, Varactor Diode Test - Phase II (Microwave Assoc.)

The contract has been executed. Initial screening measurements are scheduled to begin on July 5, 1967. Completion of testing is scheduled for July 1969.

11. ZPP-2107-GEN, Fuse Test (Wyle Labs.)

The parts are now at the 4,300-h period in life-testing. To date there has been no significant catastrophic effects caused by heat sterilization. There have been numerous failures with the Littelfuse parts, although this must be discounted as the contractor inadvertently degraded the parts during the soldering operation while mounting the parts on the test boards. Consequently, it has been decided to retest these parts under a separate contract. The new contract is scheduled to be executed by August 9, 1967.

12. ZPP-2110-GEN, Thermistor Test (Sperry Utah)

The parts have now completed 4,100 h of life-testing. To date there have been no significant catastrophic effects caused by heat sterilization. Several problems have been encountered. The Victory 35A5 thermistors have had numerous failures due to mounting problems. They are too small and delicate to use normal mounting methods. The leads are 0.001-in. diam. and the body is 0.010-in. diam. If it is necessary to use these parts in equipment, a special research test program would be necessary, although the other three Victory thermistor types are performing very well. The Texas Instrument TM 1/8, 10Ω sensistors have been opening and the cases cracking during the 0°C measurements. The Yellow Springs Instrument (YSI) thermistors are severely drifting during the 0°C measurements. This is a very poor characteristic for a thermistor. At the present it does not appear that the T.I. sensistors or the YSI thermistors are suitable for inclusion in the SPL. The program is scheduled to be completed by August 1968.

13. ZPP-2113-GEN, Transistor Test (Motorola)

The parts have now completed 10,000 h of life-testing. The trend outlined last report period has not changed. Since the 3,000-h period the parts have continued having excessive parametric drifts and a few random catastrophic failures. There is no significant evidence that heat sterilization has catastrophically degraded the parts. The program is scheduled to be completed by August 1967. Although the program has not been completed, the following conclusions can be drawn:

(a) Heat sterilization at 145°C had no significant effect on the catastrophic failures as of the 10,000-h measurement period, although there is evidence of parametric drift during life-testing.

(b) Power applied versus storage groups displayed significantly more failures for the power applied groups with several of the transistor types.

(c) A very high incidence of parametric failures points out the need to use hi-rel parts for spacecraft hardware, which include burn-in and environmental stress screens.

(d) The overall difference in performance between the manufacturers was negligible.

(e) The predominant catastrophic failure mode was "purple plague" leading to junction bond failures. Otherwise generally poor workmanship was indicated by the failure analysis.

(f) The PNP devices had twice the percentage of parametric failures than the NPN devices had. There were insufficient high-power part types to make a comparison with the low-power types.

(g) The predominant parametric failure modes for the NPN and PNP devices were excessive junction leakage and degraded current gain during life-testing.

(h) The manufacturers' parametric data sheet specifications are not usually realistic. This is evidenced by the high number of initial parametric failures, and the difficulty the manufacturers have in supplying devices to their own data limits, when measurement data are required on the purchase order.

(i) In the instances where the manufacturers were contacted regarding their failures and poor workmanship, no known corrective action was initiated by them.

The contract modification to add on 14 more state-of-the-art transistor types has been executed. Initial screening measurements are in progress. To date there has been insufficient information available to form any conclusions regarding the add-on transistor types. The add-on test is scheduled to be completed by March 1969.

14. ZPP-2116-GEN, Crystal Test (Philco WDL)

Initial measurements have been completed, and the parts are now in environmental testing. To date there have been insufficient data available to form any conclusions. The program is scheduled to be completed by March 1968.

15. ZPP-2119-GEN, Relay Test

Static acceleration test measurements have been completed and low temperature operation testing is in progress. To date there has been insufficient information available to form any conclusions. The program is scheduled to be completed by February 1969.

16. ZPP-2123-GEN, Microcircuit Test - Phase II (Litton Systems)

Postscreening measurements are in progress, and they are scheduled to be completed by July 10, 1967. There has been insufficient information available to form any conclusions.

17. ZPP-2122-GEN, Linear Microcircuit Test (JPL)

The postheat sterilization measurements have been completed. To date there has been insufficient information available to form any conclusions. The program is scheduled to be completed by May 1968.

18. ZPP-2124-GEN, Inductor Test

The 4, 000-h measurements have been completed. The trends outlined in the last report have continued. As of 4, 000 h, the following conclusions can be drawn:

(a) Approximately 16% of the audio and low-frequency inductors manufactured by United Transformer Corporation experienced no measurable inductance or Q. The insulation broke down during dielectric tests.

(b) Approximately 13% of the audio transformers manufactured by Dresser Transformer Co. experienced severe physical damage resulting in electrical breakdown. Although special high-temperature transformers were ordered, the manufacturer sent standard types.

(c) Approximately 15% of the power transformers manufactured by Coast Coil Corp. experienced insulation breakdown.

(d) Epoxylite 295-1, used by several manufacturers, severely crazed and cracked.

Although the manufacturers were advised of the heat requirements, many of them used improper materials or poor construction techniques. The above problems could undoubtedly be corrected by redesign, but at this point in the test program there are sufficient remaining part types to preclude the necessity of corrective action.

19. ZPP-2118-GEN, Ethylene Oxide Test - Phase III (Hughes Aircraft)

Testing is scheduled to start in July 1967. Completion of testing is scheduled for January 1969.

20. ZPP-2125-GEN, Screening Development Program - Task I (TRW)

The contract has been executed. Initial measurements have been completed. Physical analysis is now in progress. To date there has been insufficient information available to form any conclusions. This program is scheduled to be completed by May 1968.

21. ZPP-2010-SPL, Sterilization Parts List

Revision D is scheduled to be released approximately September 1, 1967. This revision will add and delete part types in accordance with the latest test information.

PUBLICATIONS DURING REPORT PERIOD

Papers Presented at Meetings and Symposia

1. Visser, J., "Current Results of the JPL Sterilization Test Program," IEEE Reliability Symposium, January 1967.

JPL SPS Contributions

1. Martin, K., "Transistor Sterilization Test Program 2,000 Hour Interim Report Summary," SPS 37-43, Vol. IV, February 1967.

Contractor Reports, Interim and Final

1. Andrews, D., Thermistor Sterilization Test Program 2,000 Hour Interim Report, May 1967.
2. Lammerding, G., Fuse Sterilization Test Program, 2,000 Hour Interim Report, May 1967.
3. O'Brien, J., Inductor Sterilization Test Program, 2,000 Hour Interim Report, June 1967.
4. Cooper, W., Relay Sterilization Test Program, 2,000 Hour Interim Report, October 1967.
5. Reinke, Dale, Transistor Sterilization Test Program Final Report, July 1967.

COMPONENT FAMILY	SPECIFICATIONS ZPP - GEN	SPECIFICATIONS IN PREPARATION	SPECIFICATIONS COMPLETED	CONTRACT NEGOTIATION AND APPROVAL	CONTRACT AWARDED	VISUAL INSPECTION	TEST EQUIPMENT AND FIXTURES	INITIAL MEASUREMENTS	STERILIZATION TEMPERATURE AND MEAS.	ENVIRON. TESTING AND MEASUREMENT	START LIFE TEST	100 h MEASUREMENT	250-h MEASUREMENT	500 - h MEASUREMENT	1,000-h MEASUREMENT	2,000-h MEASUREMENT	4,000-h MEASUREMENT	6,000-h MEASUREMENT	8,000-h MEASUREMENT	10,000-h MEASUREMENT	250-h FOLLOW-ON MEASURMENT	FINAL REPORT	CONTRACT CLOSED OUT	
CAPACITORS (PHASE II)	2101																					Δ		16,000*
	2108						Δ																	—
FIXED RESISTORS (PHASE II)	2102																					▽		16,000
	2112								▽															—
TRIMMING RESISTORS (PHASE II)	2103																					Δ		10,000
	2109								Δ															—
VERACTOR DIODES (PHASE II)	2105																					Δ		10,000
	2106				Δ																			—
GENERAL DIODES ADD-ON TEST	2104																	▽						6,000
					Δ																			
DIGITAL MICROCIRCUIT (PHASE II)	2121																							10,000
	2123							Δ																
FUSES	2107																▽							4,300
CRYSTALS	2116									Δ														—
RELAYS	2119									Δ														—
MAGNETICS	2124																▽							4,000
THERMISTORS	2110																▽							4,000
ETO-PHASE II	2118			Δ																				—
LINEAR MICROCIRCUIT	2122								▽															—
SCREENING	2125							▽																NA
TRANSISTORS ADD-ON TEST	2113																			▽				10,000
								Δ																—
TEMPERATURE MATRIX TEST	2127							Δ																

Δ = IN PROGRESS ▽ = COMPLETED * = FOLLOW-ON LIFE TEST OF CRITICAL TYPES NA = NOT APPLICABLE

Fig. 1. Test status summary sheet as of June 30, 1967

STERILIZABLE POLYMERS

NASA Work Unit 186-58-13-02-55
JPL 384-83801-2-3510

Hugh G. Maxwell

OBJECTIVE

The long-range objective of this work unit is to determine the effects of ethylene oxide (ETO) decontamination and heat sterilization on spacecraft polymeric products. The objective during this fiscal year is to establish a comprehensive list of polymeric products for spacecraft construction that can withstand ETO decontamination and heat sterilization to Voyager requirements.

PROGRESS

Work is continuing on JPL Contract 951566 awarded to Autonetics Division of North American Aviation, Inc., on October 18, 1966. This contract consists of a test program to evaluate the effects of ETO decontamination and heat sterilization on approximately 180 polymeric products. The evaluation process is to test and compare the results of each product for mechanical, physical, and/or electrical properties before and after exposure to Voyager ETO decontamination and heat sterilization per Ref. 1. To date, procurement is complete, specimen preparation is 85% complete, ETO exposure 50% complete, heat exposure 25% complete, and specimen testing approximately 25% complete. Completion scheduled for July 31, 1967, has slipped approximately 2 mo.

The JPL Polymer Research Section has completed work on approximately 34 polymeric products being evaluated to support other sterilization efforts. The results of these tests showed 23% of these products to be compatible, 15% to be marginal, and 62% to be not compatible with Voyager sterilization requirements. These compatibility ratings were based on relative retention of mechanical, physical, and electrical properties after exposure to Voyager sterilization requirements. Glass fabric laminate, polyimide film, and silicone rubber products tested were rated compatible, while polyurethane, acetal plastic, nylon plastic, epoxy-polyamide adhesive, polyester adhesive, polyester film, and polyvinyl fluoride film products tested were rated marginal or incompatible. These results indicate the revised Voyager sterilization requirements per Ref. 1 to have a much more severe effect on polymers than the previous requirements per Refs. 2 and 3. The Polymer Research Section is also completing evaluation of five polymeric products exposed to higher and lower heat sterilization temperatures than Voyager requirements (viz., 6 cycles of 59 h each at 150°C and 6 cycles of 246 h each at 120°C.) These results will be used to evaluate the relative effects of different sterilization regimes on polymers. In addition, the Polymer Research Section is supporting other JPL divisions by making their ETO decontamination and heat sterilization facilities available for the test of small parts and components.

FUTURE PLANS

In FY 1968, after completion of the above work, it is planned to shift work to an existing contract at Stanford Research Institute: JPL Contract 950745, "Polymers for Spacecraft Applications," NASA Work Unit 186-68-13-04. This work will be to determine the effects of space environments on materials after sterilization. The planned approach is (1) to evaluate polymeric products for outgassing after exposure to sterilization and (2) to evaluate polymeric products for electrical, mechanical, and physical properties after sterilization and exposure to a vacuum-thermal simulated space environment.

REFERENCES

1. JPL Specification Vol-50503-ETS, "Voyager Capsule Flight, Equipment, Type Approval and Flight Acceptance Test Procedures for Heat Sterilization and Ethylene Oxide Decontamination Environments."

2. JPL Specification GMO-50198-ETS, "Compatibility Tests for Ethylene Oxide Decontamination Requirements."

3. JPL Specification XSO-30275-TST-A, "Compatibility Test for Planetary Dry Heat Sterilization Requirements."

PUBLICATIONS DURING REPORT PERIOD

1. Contractor monthly and quarterly reports.

ANTICIPATED PUBLICATIONS

1. Kalfayan, S. H., Campbell, B. A., and Silver, R. H., "The Effects of Ethylene Oxide Decontamination and Dry Heat Sterilization on Polymeric Products."

2. Kalfayan, S. H., and Campbell, B. A., "The Effects of Ethylene Oxide Decontamination and Dry Heat Sterilization on Insulators Used in Spacecraft".

3. Lee, S. M., "Evaluation of the Effects of Decontamination and Sterilization Treatment on Spacecraft Polymeric Materials".

4. Contractor monthly reports.

STERILIZABLE ELECTRONIC EQUIPMENT PROCESSES

NASA Work Unit 186-58-13-03-55
JPL 384-85301-2-3570

R. F. Holtze

OBJECTIVE

The objective of this work unit for the long-range period is to develop and qualify sterilizable material applications and processes for assembling and packaging of electronic equipment. Information will be obtained on the effect sterilization has on the physical or chemical interaction between processing materials and components that would affect the functional use of such subassemblies. Future objectives consist of determining the effects of additional materials and processes on components in those areas which were found to be deficient in previous testing.

ACCOMPLISHMENTS

JPL Contract 951214, covering an investigation of sterilizable electronic equipment processes by Northrop Space Laboratories, was completed on September 16, 1966, and a final report issued.

Results of this investigation indicated that embedment compounds did affect the functional parameters of certain components embedded in them, as a result of the sterilization cycles. The test data indicated that embedment compounds exert a definite pressure on embedded components. This pressure is increased as a result of the temperature sterilization cycles. This increased pressure has an effect on parameters of certain components, notably the resistors and capacitors. Further work is being accomplished in this area to evaluate sterilization effects on additional embedment materials and the effect that these sterilized materials have on the parameters of certain selected components.

This additional work to determine sterilization effects on embedment compounds will be done under an outside contract. A statement of work has been prepared outlining the objectives and procedures to be followed in this investigation.

PLANNED ACTIVITIES

It is anticipated that a contract will be issued during the first half of FY 1968 covering the follow-on work listed above. The contract covering this investigation will include the following points:

A total of five embedment materials or systems will be included. Selection of these materials will be based on (1) Suitability for sterilization as determined from past investigations, vendor's data and type of material (2) Suitability for general use as an embedment material (3) Vendor's information or other test data on the amount of pressure exerted by the candidate materials on components.

The materials will be selected so that a comparison can be obtained between materials exerting varying amounts of pressure on the components as a result of sterilization.

A total of 13 different components have been selected for this investigation. All of these components are from the sterilizable component list issued by JPL. The components include 4 resistors of various types, 3 different types of capacitors, 2 types of fuses, 2 types of inductors, 1 diode, and 1 thermistor. It is believed that these components are of an adequate variety to determine what effect the combination of embedment materials and sterilization have on the operating parameters of the components. A total of 20 parts of each of the 13 different types will be embedded in each of the five material systems being tested. A control module containing unembedded components will also be included. The operating parameters of a particular component will be determined prior to embedment, after embedment, after sterilization, and after exposure to low temperatures (0 and -35°F). The effects of sterilization, and low-temperature exposure can be compared not only between the various types of components, but also between the various systems of embedment materials.

In addition to the embedded component modules, test work will also be done to determine the actual pressure that the different embedment materials do exert. This determination will be made by means of the thermometer-embedment method, and also by means of pressure-calibrated carbon composition resistors. Pressures will be determined by both methods for all five embedment materials being tested. This pressure will be determined after embedment, after sterilization, and also at temperatures of 0 and -35°F.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

STERILIZATION OF IMPACT LIMITERS

NASA Work Unit 186-58-13-04-55
JPL 384-85701-2-3510
A. B. Sorkin

OBJECTIVE

The broad objective of this program is to evaluate the effects of sterilization on promising impact-limiter materials that are candidates for planetary hard landers. The specific objectives of this work were: (1) to continue to evaluate the effects of ethylene oxide decontamination and thermal sterilization treatments on balsa wood, (2) to continue to develop methods for improving balsa wood's resistance to thermal degradation, (3) to develop procedures which can be used for grading and selecting balsa wood with uniform energy dissipation properties, and (4) to evaluate the effects of sterilization on improved limiter materials which are under development.

PROGRESS

The activities during this report period were concerned principally with measuring certain mechanical and physical properties of balsa wood in order to determine if a simple test could be utilized in identifying wood with the highest energy dissipating capacity. In addition, the effects of ethylene oxide decontamination and thermal sterilization on balsa wood's energy-dissipating capability were evaluated to obtain data for design of sterilized balsa wood limiters. A feasibility study of improving energy dissipation by monomer impregnation and irradiation was completed.

The material evaluated in the test program was ordered from Balsa Ecuador Lumber Company in the form of 3-1/4x3-1/4x36 in. balsa sticks per MIL-S-7998 in two density ranges: 7 ± 1 lb/ft^3 and 9 ± 1 lb/ft^3. Three hundred sticks in each density range were received, finished to 3x3x36 in., serialized, and inspected for defects.

Evaluation of sticks stabilized at 6 to 8% moisture content included determination of gross density and bend strength (Young's modulus). One block 3x3x3 in. was cut from each stick and crush-tested in the direction of maximum strength, i.e., parallel to the grain. A standard wood hardness test was performed on each stick in a direction parallel to the grain. Basic density and true moisture content was derived by oven-drying at 105°C 600 blocks to 0% moisture. A group of 50 oven-dried blocks was crush tested. Several tests were performed on only a small sampling of the 600 sticks including toughness, modified Izod impact, and dynamic modulus.

Attempts to correlate results of the various tests to specific crush energy have been complicated by considerable variation of values within a given test sample. The variation is due, at least in part, to the period growth cycles and associated cell structure variations. Data scatter increases substantially if the zone being evaluated is not large enough to cover several growth rings (approximately 1/2- to 1-in.-wide growth rings are typical).

Sterilization cycles were used on one block from each stick in a manner that would simulate impact limiter sterilization per JPL preliminary Spec. VOL-50503-ETS. The sterilization consisted of six 28 h at 50°C cycles in a 12% ethylene oxide -- 88% freon mixture followed by six 92 h at 135°C cycles in dry nitrogen.

The sterilized blocks were crush-tested and resultant specific energy values compared to "as received" and oven-dried specific energy values. The principal effect of sterilization appears to have been moisture removal with no decrease in energy-dissipating properties.

Computer-aided statistical analysis is being utilized to obtain design values for sterilized balsa wood and to determine if sufficient correlation exists between crush test values and the other test results derived in this program. The services of Dr. Arno P. Schniewind, a consulting wood technologist from the University of California, were utilized throughout this program.

Attempts to improve balsa wood's energy-dissipating properties by impregnation with a monomer followed by irradiation induced polymerization have not been encouraging. Samples treated with acrylic monomers by West Virginia University were too heavily loaded with plastic (31 to 79% increase) to overcome the weight penalty in calculating specific energy. Samples impregnated and irradiated with an unspecified monomer by American Balsa Wood Corp. had less than 10% weight increase but also exhibited reduced specific energy values. Evaluation of a second group of samples from each source is in progress.

FUTURE PLANS

This work unit will not be funded during FY 1968.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

1. Sorkin, A. B., "Effects of Sterilization on Planetary Impact Limiter Material Energy Dissipating Properties," (in press).

STERILIZABLE ELECTRICAL SOLDERED AND WELDED JOINTS

NASA Work Unit 186-58-13-05-55
JPL 384-85001-2-3570

R. F. Holtze

OBJECTIVE

The objective of this work unit for the long-range period was to determine the effects of sterilization treatments on various material combination joints that are soldered or welded for connections in electronic equipment and to develop improved joining methods or more compatible material combinations in the deficient areas. An additional objective was to determine the effect of sterilization on the solderability of various lead materials.

ACCOMPLISHMENTS

Investigation of sterilization effects on soldered and welded joints and the solderability of lead materials after sterilization has been completed and covered in previous reports. Detailed results are covered in Hughes Aircraft Corporation Report P-65-117 (NASA Accession N66-12854).

JPL Contract 951663 was signed with the Hughes Aircraft Corporation on August 11, 1966. Total amount of the contract was $16,963. This contract covered the evaluation of three high-strength solders for (1) stress-rupture strength at room and sterilization temperatures, (2) ultimate strength, (3) electrical resistance, (4) metallurgical properties, and (5) application characteristics. The solders selected for test are in accordance with QQ-S-571d and consist of Sn 96 (tin 96% and silver 4%), Sn 62 (tin 62%, silver 2%, and lead 36%), and Sb 5 (tin 94%, antimony 4 to 6%, and lead 0.2%). Sterilization effects were determined at 135°C and also at 145°C.

The final report covering this investigation is due from Hughes Aircraft Corporation by June 23, 1967, but was not available at the time of this semiannual report.

Preliminary data on the stress rupture strength of solder joints at sterilization temperatures is summarized in Table 1. This data is from the monthly reports submitted by the contractor, and indicates that solder joints can be obtained through the use of high-strength solders that will support a load of 3- to 4-lb during thermal sterilization.

FUTURE PLANS

The complete report will be studied and the results analyzed. Preliminary indications are that the three solders being tested will provide satisfactory stress-rupture strengths at sterilization temperatures and that further work will not be required. Completion of the present investigation will accomplish the objectives of this work unit and no further activities are planned in this area.

Table 1. Stress rupture strength of connector solder joints[a]

Solders	Room temperature for 552 h		135°C for 552 h		145°C for 108 h	
	Type 1 pins	Type 2 pins	Type 1 pins	Type 2 pins	Type 1 pins	Type 2 pins
Sn 63 (63% tin, 37% lead)	7.63 (108 h)	10.5 (108 h)	less than 0.4	data not available	--	0.75
Sn 96 (96% tin, 4% silver)	9.1	9.1	2.0	data not available	2.0	3.67
Sn 62 (62% tin, 35.8% lead, 2% silver, 0.2% antimony)	7.0	11.2	0.6	data not available	Less than 0.4	0.6
Sb 5 (95% tin, 5% antimony)	9.1	9.1	3.0	data not available	2.7	4.0

[a]Figures indicate the load in pounds that the connector solder joint will support without breaking for the time and temperature listed. Type 1 and Type 2 connector pins are of similar geometry but from different vendors.

PUBLICATIONS DURING REPORT PERIOD

Contractor Reports

1. Keister, F. Z., and Holley, J. H., Test Program to Study Thermal Sterilization Effects on Connector Cup Solder Joints and Determine the Operating Parameters for Application of Solders, Hughes Aircraft Corp., Report P-67-130, June 1967 (JPL Contract 951663).

ANTICIPATED PUBLICATIONS

None.

STERILIZABLE CONNECTORS, WIRES, AND CABLING ACCESSORIES

NASA Work Unit 186-58-13-06-55
JPL 384-85801-2-3570

R. W. Lester

OBJECTIVE

The long-range objective of this work unit is to assure the availability of sterilizable flight-type multipin electrical connectors, electrical wires, cabling accessories, and RF connectors and cables. This broad goal has been divided into three parts. The first is to establish the evaluation procedures and criteria for acceptance of the kinds of parts under study for use on sterilizable spacecraft. The second is to determine the acceptability of specific parts through testing. The third is to determine the suitability of combinations or assemblies of individually acceptable parts for exposure to decontamination and sterilization processing.

CONTRACTS

The first approach for the accomplishment of testing and sterilization exposure was to contract for this work to be accomplished outside. Because of earlier problems in obtaining acceptable proposals and delays in starting tests, it was decided to perform testing and heat sterilization at JPL. Ethylene oxide decontamination exposure is to be accomplished at outside facilities because suitable equipment is not scheduled to be available at JPL when needed. The parts to be tested have been divided into two groups because of differing test requirements. RF connectors and cables are to be evaluated as one unit. Multipin connectors, wires, and cabling accessories assembled into representative harnesses will make up the second unit.

RF CONNECTORS AND CABLES

A test plan including detailed descriptions of test assemblies has been written. All parts for three sets of test assemblies have been ordered, and all but a few parts are on hand. Approximately 75% of the assemblies have been completed. A time-domain reflectometer has been purchased to provide the means for measuring and recording voltage standing wave ratios and changes in impedances. JPL tests indicate that this instrument provides increased accuracy over previous methods and that many manhours will be saved through its use. Testing of RF assemblies is to be accomplished in the first FY 1968 quarter. A purchase order for outside ethylene-oxide exposure is being negotiated.

MULTIPIN CONNECTORS, WIRES, AND ACCESSORIES

Five identical harnesses which incorporate candidate connectors, wires and accessories are being fabricated. Wire lists and plans are complete. The cable fixtures have been made and the cables are in process. All test items have been ordered, and all parts, except one kind of connector, are on hand. Testing and sterilization exposure is to be completed in the second quarter of FY 1968.

CAPSULE SYSTEM ADVANCED DEVELOPMENT

Representative connectors, wires, and accessories are to be furnished for a feasibility model entry system and lander package. In addition, technical assistance will be given to those who are designing and fabricating portions of the CSAD which incorporates connectors, wires, and cables.

MANPOWER AND PLANNED EFFORT

The decision to perform most of the tasks for this work unit at JPL is expected to result in a reduction in the total costs to evaluate candidate parts. Contract fund requirements are expected to be nil. On the other hand, there has been an increase in technician and administrative manhours used to design and fabricate the test specimens. Pre- and post-exposure testing and heat sterilization will require a continuation of high levels of effort in these areas during the first part of FY 1968.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

STERILIZABLE ELECTRONIC ASSEMBLY
NASA Work Unit 186-58-13-07-55
JPL 384-80201-2-3570

E. R. Bunker, Jr.

OBJECTIVE

The long-term objective of this work unit is to evaluate and test typical and functional electronic assemblies that utilize a combination of sterilizable subassembly design configurations after exposure to the sterilization environment, and thereby determine any possible degradation due to unpredicted interaction of component elements. The supporting objectives for FY 1967 were: (1) to test and evaluate the complete electronic assembly design developed in the work unit "Modular Electronic Packaging Advanced Development," NASA 186-68-10-09, after exposure to the sterilization environment, (2) to test and evaluate all of the existing JPL sterilizable subassembly design configurations after sterilization within an electronic assembly, and (3) to test and evaluate a sterilizable interconnect harness subassembly after sterilization cycles within a complete electronic assembly.

PROGRESS TO DATE

Up to a month ago, very little was accomplished on this work unit for two reasons. As noted above, it was planned to sterilize and test electronic modules which were part of a functional electronic subassembly developed on other work units. Because of various delays, the design of these modules has not progressed as far as desired. Also, some preliminary work was not accomplished because of manpower limitations.

The sterilization requirements for the electronic packaging for a typical hard lander have been established. The heat sterilization requirement, which is the more rigorous for the complete electronic modules, is 6 cycles of 96 h each at 135°C.

PLAN FOR FUTURE WORK

Typical electronic modules employed in electronic subsystems will be fabricated and exposed to the sterilization environment to determine the degree of degradation, if any. Typical cable harness assemblies will be fabricated and tested to determine the effect of sterilization. After the modules have been proven, they will be assembled into a typical electronic subsystem and tested to determine possible interaction or degradation as a subsystem. A complete electronic assembly developed under "Modular Electronic Packaging," NASA Work Unit 186-68-10-09-55, will be fabricated and tested. This assembly will include an operational sterilizable wiring harness along with the operational wirecon subassemblies developed in the above work unit. Also, operational sticks composed of I. C. modules and discrete components developed in "Microelectronic Packaging Advanced Development," NASA Work Unit 125-25-03-02-55, will be sterilized. These modules will be assembled in this assembly and tested before and after sterilization to determine if any degradation occurred. Care will be taken to see that these two programs complement each other rather than overlap.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

MATRIX TEST OF STERILIZABLE PIECE PARTS

NASA Work Unit 186-58-13-08-55
JPL 384-80401-2-3540

J. Visser

OBJECTIVE

The objective of this task is to support the NASA thermal sterilization policy by studying the temperature-time relationships, the effects of different numbers of temperature cycles, the effects of different rates of temperature change, and the effects of different storage periods at temperature. These relationships of the sterilization environments will be studied for their effects on the reliability of some representative electronic component piece parts during long life.

PROGRESS

ZPP-2127-GEN, Capacitor Matrix Test (Litton Systems)

The contract for performance of the original test matrix was executed January 19, 1967. Immediately upon execution of the contract, negotiations for a contract modification (ZPP-2127-GEN-A, Mod. I) were initiated and executed in order to revise the original test matrix (see Tables 1 and 2). It was determined that the revised matrix would more realistically represent the present time-temperature sterilization requirements. The initial screening and postscreening measurements have been completed for the Rev. A parts. The parts are now being grouped and prepared for the initial sterilization testing measurements. A second modification (ZPP-2127-GEN-B, Mod II) is in preparation. This modification will add three more test matrices to the program (see Tables 3, 4, and 5), which will increase the total parts under test by 3,600. Contract negotiations for Modification II began in early May 1967, and the modification should be executed during July 1967.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

Table 1. Original test matrix

Time	105°C	115°C	125°C	135°C	145°C	160°C
36 h	Group A 30 parts (typical)	Group B	Group C	Group D	Group E	Group F
65 h	Group G	Group H	Group I	Group J	Group K	Group L
94 h	Group M	Group N	Group O	Group P	Group Q	Group R

Table 2. Revised test matrix

25°C	105°C	115°C	125°C	135°C	145°C	160°C	Time
Group A[a] 30 Parts (Typical)						Group B	3 ±5 min
					Group C	Group D	9 ±15 min
				Group E	Group F	Group G	22 ±30 min
					Group H		36 ±30 min
			Group I	Group J	Group K		53 ±1 h
				Group L			92 ±1 h
		Group M	Group N	Group O			132 ±1 h
	Group P	Group Q	Group R				336 ±1 h

[a]Group A is the control group and does not receive heat cycling.

Table 3. Number of temperature cycles matrix

Condition	Number of temperature cycles					
	3	6	9	12	15	18
36 h at 145°C	Group AA	Group AB	Group AC	Group AD	Group AE	Group AF
92 h at 135°C	Group AG	Group AH	Group AI	Group AJ	Group AK	Group AL

Table 4. Temperature storage matrix

Temperature	Storage, h					
	36	92	200	300	400	500
145°C	Group CA	Group CB	Group CC	Group CD	Group CE	Group CF
135°C	Group CG	Group CH	Group CI	Group CJ	Group CK	Group CL

Table 5. Time to reach temperature matrix

Temperature	Time to reach temperature, min						
	120	90	60	30	15	7-1/2	Shock
145°C	Group BA	Group BB	Group BC	Group BD	Group BE	Group BF	Group BG
105°C	Group BI	Group BJ	Group BK	Group BL	Group BM	Group BN	Group BO

SPACECRAFT AND CAPSULE EQUIPMENT DEVELOPMENT (186-68)

PLANETARY ENTRY AND LANDING STRUCTURES

NASA Work Unit 186-68-01-01-55
JPL 384-60101-2-3530
A. Knoell
J. Brayshaw

OBJECTIVE

The objectives of this task are to study and develop the application of materials with high energy-dissipating capabilities to the protection of spacecraft and/or capsules from impact loads during terminal landing. Recent success in development of phenolic honeycomb as an energy-dissipating structure indicates that study of doubly curved configuration characteristics, investigation of fabricating techniques of double-curved arrays, and development of analytic capability to predict dynamic response should be initiated in FY 1967. Also, aerodynamic decelerators will be investigated as follows:

1. Technology Appraisal. Updated appraisal of modern aerodynamic decelerator technology applicable to planetary entry use.

2. Landing Mission Integration. Preliminary studies of the effectiveness of integrating such technology into a planetary landing system.

THEORETICAL RESPONSE PREDICTIONS

Spherical Honeycomb Impact Limiter

A computer program has been developed to provide a numerical solution to the mathematical equations generated for predicting the static and dynamic response of a spherical honeycomb (Dovetail) impact limiter during crushing against rigid surfaces of flat, concave, and convex curvature. The response characteristics include the development of the crushing force as a function of honeycomb material properties and limiter geometry, and the determination of the maximum impact velocity and deceleration experienced by a given spherical limiter. Additional output of the computer program includes the number of stress wave reversal cycles generated during impact and the deceleration level at which the so-called "cannonball" phenomenon occurs.

The computer program is operational as far as the flat and concave surface curvatures are concerned. The case of convex surface curvature is still under development.

It is intended that the results of the effort be published as a JPL TR during FY 1968. Publication is pending, however, due to better definition of the structural properties of the honeycomb material (Dovetail) needed for the analytical model.

Stress Wave Effects

Work has been countinuing on a sharply reduced level of effort to develop the characteristic technique for multidimensional wave propagation in elastic solids. This technique has now been applied to various simple idealized problems to establish the extent of its applicability to complex problems. The results compare in all cases favorably with those obtained by other procedures. This technique is now being extended to be applicable to the propagation of stress waves in complex structures such as batteries under inpact loading.

Disc Impact Limiter - Capsule System Advanced Development

An analytical investigation of the dynamic response of a disc-type limiter has been initiated. This limiter is shown schematically in Fig. 1. The analysis is directed primarily toward determining the maximum deceleration experienced by the limiter as a function of the initial conditions of impact attitude, velocity, limiter geometry, and material properties.

A significant feature of this analysis is the development of the crushing force as a function of the energy-dissipator material properties, limiter geometry, and crushing attitude. Data to be obtained from static tests of several limiters will be extremely valuable in improving this functional relationship.

A solution based on the above-mentioned analysis has been generated for impacts against flat unyielding surfaces. This solution is currently being programmed to expedite numerical calculations. It is expected that the computer program will be operational in the first quarter of FY 1968. Subsequent analytic effort during FY 1968 will be directed mainly toward incorporating the effects of surface curvature and rock penetration in the mathematical model used for the limiter dynamic response prediction.

Dovetail Phenolic Honeycomb

Under the terms of a contract with the General Electric Company (JPL Contract 951172) significant milestones have been achieved in the development of a nonhexagonal phenolic honeycomb known as Dovetail (see previous semiannual report for description). These milestones related primarily to the resolution of material processing difficulties experienced in the fabrication of Dovetail. Having resolved these difficulties, several Dovetail honeycomb specimens have been fabricated and statically tested. Preliminary results show that a crushing stress of approximately 1200 psi at a density of 11.5 pcf has been obtained for Dovetail. This compares with a crushing stress of approximately 1700 psi at the same density in hexagonal phenolic honeycomb. An improvement is expected, however, in the Dovetail properties by using a thin dipping technique during Dovetail fabrication and constructing the Dovetail of a smaller cell size.

Currently, several logs of Dovetail are being fabricated from which spherical Dovetail honeycomb specimens will be built and subsequently statically tested. This effort should bring Dovetail to a developmental status where the material can be satisfactorily used as an energy dissipator. Also at this point several of its structural response properties will be determined.

Impact Limiter Development

A total of six impact limiters of the configuration shown in Fig. 1, consisting individually of balsa wood and hexagonal phenolic honeycomb as the energy-dissipating materials, have been fabricated and tested. Three balsa wood limiters were fabricated in-house, whereas three phenolic limiters were fabricated by G. E. under JPL Contract 951172. The density of the energy-dissipating materials was approximately 7 pcf.

Of each type of limiter material, one specimen was used for static testing and two specimens were used for dynamic testing. One static test of each material type was performed at crushing attitudes of 67.5 and 90 deg relative to a flat surface. The test results are presented in Table 1.

Table 1. Test results of limiter material

Test	Material			
	Balsa wood limiter		Hexagonal phenolic limiter	
Crushing attitude, deg	67.6	90.0	67.5	90.0
Peak static force, lb	30,000	49,800	30,000	49,800
Maximum usable stroke, in.	2.46	2.34	2.42	2.40
Energy dissipated, ft - lb	3450	5430	2780	4530

A direct comparison of the static response of both types of impact-limiter material indicates that the performance of both is relatively comparable and satisfactory. It should be noted that for all practical purposes the phenolic honeycomb specimen was heat-sterilized, whereas the balsa wood specimen was not; and that in an effort to expedite honeycomb material delivery for limiter fabrication, the hexagonal phenolic honeycomb was not of the more optimum type developed under JPL Contract 951172. Both of the above factors tend to enhance the performance of the phenolic limiter.

Two dynamic drop tests of each type of limiter material were performed at impact attitudes of approximately 0 (edge) and 90 deg (flat) and at impact velocities of approximately 105 and 95 ft/s, respectively. The test specimens were dropped onto an asphalt roadway surface and were photographed and instrumentated for recording continuous deceleration-time response histories. In addition, approximately one test of each type of limiter material was conducted as described above, except the test specimens were dropped onto a sand bed of approximately 6-in. depth.

Since the tests were performed very recently, it has not been possible to fully evaluate the test data. Preliminary results indicate that, in general, the deceleration levels were of the order of 1500 and 2500 earth g for the flat and edge hard-surface tests, respectively. The sand drop tests gave deceleration levels

approximately half of the above values, respectively. The performance of both types of limiter material appeared similar, except that the structural integrity of the phenolic limiters was slightly better.

It is intended that a detailed study of the photographic and dynamic response data be made in the immediate future in order to provide an engineering basis for understanding and improving on the design of the energy-dissipating system. Also planned are additional static and dynamic tests of sterilized impact limiters of both types of material. The phenolic specimens will be fabricated of the more optimum honeycomb type.

Engineering evaluation of the change from a spherical to a disc configuration for this limiter coupled with the test data of the disc limiter configuration obtained to date indicates that no requirement exists for a structural cover for this impact limiter. Subsequent specimen testing and data evaluation, particularly of the balsa wood limiter, should verify this conclusion concretely. Thus, no effort is intended regarding cover design and development unless proven necessary.

PLANETARY ENTRY AERODYNAMIC DECELERATORS

Liaison with government agencies and industrial companies conducting aerodynamic decelerator development has been maintained. Latest demonstrated capabilities have been incorporated into plans for future planetary landing missions. The supporting hardware of successful late decelerator models has been examined for compatibility with proposed Mars landing capsules.

In particular, the disc-gap-band parachute, one of the types under flight test investigation by Langley Research Center, appears the best suited for Mars landing. It has shown excellent inflation, stability, and drag at Mars-like air density and low supersonic deployment velocity. In-flight oscillation of the payload has been less than 15 deg and drag coefficients between 0.5 and 0.6 have been measured. Under capsule-decelerating forces present during Mars entry, a mortar appears well suited to be the deployment device. Some study has gone into placement of the mortar within the capsule, direction of firing with respect to capsule wake, and possible disturbances to capsule attitude.

An optimization study of the best weight combinations of parachute and balsa wood sphere impact attenuator for various capsule ballistic coefficient and lander vertical impact velocity on Mars has been completed. For capsule ballistic coefficient less than 0.16, entry velocity 23,000 ft/s, entry path angle -60 deg, and deployment Mach number between 1.0 and 2.0, the landed package weight was maximized for vertical impact velocities between 80 and 150 ft/s.

A study to predict the variations of flight conditions at deployment when using an accelerometer (dynamic pressure) sensor to initiate deployment, has been completed for the most critical Mars atmosphere model. The variations in Mach (velocity) at deployment due to the various errors considered are nominal, but they do comprise a restraint on the allowable entry ballistic coefficient.

Work has been initiated to define the development program necessary to convert raw technical feasibility into reliability under concrete applications. A first-cut list of development program requirements has been formulated. This phase of the work is being reexamined for detailed application to a future Mars landing mission.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

JPL Technical Reports

1. Knoell, A.C., Analysis of the Crushing of a Dovetail Phenolic Honeycomb Spherical Impact Limiter (in preparation).

2. Knoell, A.C., Landing Dynamics of a Disc-Shaped Impact Limiter (in preparation).

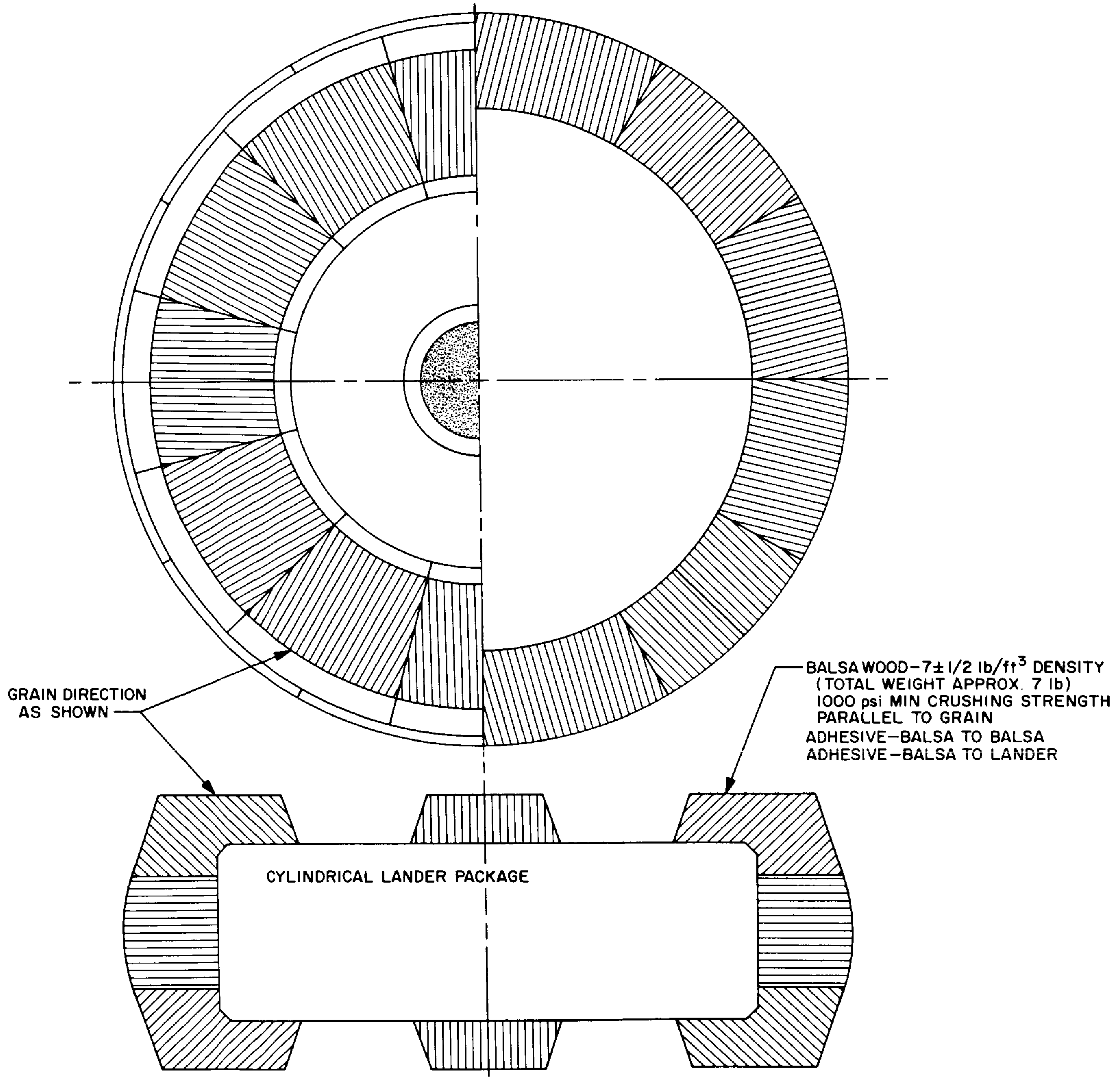


Fig. 1. Disc-type limiter

SPACECRAFT PRESSURE VESSEL ADVANCED DEVELOPMENT

NASA Work Unit 186-68-01-02-55
JPL 384-67001-2-3510

J. C. Lewis
E. Heer

OBJECTIVE

The objective of this work unit is to apply advanced technology in materials and design to development of highly efficient spacecraft pressure vessels for Voyager and other future spacecraft applications. The specific objective of this work is to apply some of the recent theoretical knowledge in fracture technology to selection of materials and design of spacecraft vessels used in applications for high-pressure gas storage, propellant tanks, and solid rocket chambers.

PROGRESS

Work on this program was delayed because manpower was unavailable during the first and second quarters of FY 1967. This was a direct result of increased manpower demands by the Mariner Venus 1967 and the Mariner Mars 1969 programs. During the latter part of the second quarter, work was begun to formulate a design hypothesis for spacecraft pressure vessels that would encompass the objectives described above. This was undertaken as a cooperative effort between the Materials Section and the Applied Mechanics Section of JPL.

Review of the literature in the fields of theoretical and applied fracture mechanics has been completed. The basic concepts of fracture mechanics have been applied to pressure vessel design. Two symposia related to applied fracture mechanics were attended during the reporting period. The first was the "ASTM Symposium on Applications Related Phenomena in Titanium Alloys" on April 18-19, 1967 at Los Angeles, and the second symposium was the "National Symposium on Fracture Mechanics" at Lehigh University in Bethlehem, Pennsylvania on June 19-21, 1967. Extensive contact has been made with leading experts in fracture mechanics throughout the aerospace industry.

Statistical interpretation of every factor affecting pressure vessel performance has produced a fundamental design hypothesis that should achieve maximum efficiency in the design of any given pressure vessel. This hypothesis is centered on application of statistical reliability methods to the basic applied fracture mechanics approach of Tiffany and Masters (see Ref. 1) as illustrated in Fig. 1. In this figure, σ is the applied stress, K_{I_c} is an intrinsic material characteristic that mathematically expresses the maximum ability of a material to resist crack growth under an applied stress, and $(a/Q)_{cr}$ is a measure of the critical size and shape that a flaw must obtain before catastrophic failure occurs. One can see from the figure that for any given material under a known applied stress, the critical flaw size can be calculated. By nondestructively determining a maximum existing flaw size, one can assure that the known flaw size does not exceed the calculated critical flaw size, thereby assuring that the pressure vessel will not fail. However, Fig. 1 is only the basic approach

used to illustrate the concept. A full discussion of the application of fracture mechanics to pressure vessel design is not practical in this report.

It has been determined that every factor involved in material selection, design, fabrication, testing, and use of pressure vessels affects one of the three parameters shown in Fig. 1. Therefore, by statistically interpreting the effect of each factor and by using statistical reliability concepts in evaluating these parameters, a pressure vessel can be designed to maximum efficiency and minimum weight.

This hypothesis was demonstrated by designing a tank to contain liquid chlorine trifluoride for 100 h at 135°C for application on the Capsule System Advanced Development program at JPL. This information will be published as a technical report at the end of this fiscal year.

FUTURE PLANS

Since this work unit is to be terminated at the end of this fiscal year, no immediate future work is planned. However, because of the potential weight reduction associated with the design hypothesis it is hoped that the program can be reinstated at a later date as the requirements for larger spacecraft pressure vessels become imminent. By FY 1969, manpower and funding may be available to permit reduction of the design hypothesis into specifications for material selection, design, and fabrication of highly efficient spacecraft pressure vessels.

REFERENCE

1. Fracture Toughness Testing and Its Applications, ASTM STP 381, p. 249-278, June 1964.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

JPL Technical Report

1. Heer, E., and J. Lewis, Pressure Vessel Design Based on Fracture Mechanics and Reliability Concepts.

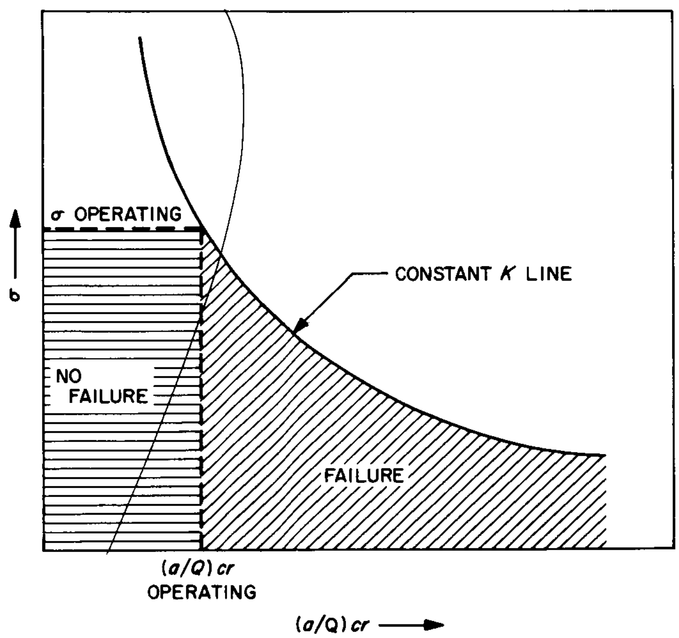


Fig. 1. Applied stress vs critical flow size

SPACECRAFT STRUCTURAL VIBRATION TEST AND ANALYSIS

NASA Work Unit 186-68-01-03-55
JPL 384-68001-2-3530

W. H. Gayman

OBJECTIVE

Until recent months the structural complexity of the Surveyor spacecraft precluded the analytical development of the high-quality mathematical models needed for rational dynamic loads analysis for the boost phase and for lunar touchdown. Recently, however, as a direct part of the Surveyor engineering effort, modal vibration analyses have been initiated using newly developed computer programs.

The objective of this work unit has been to conduct modal vibration surveys of the Surveyor Structural Test Model (S-9) in order to afford comparisons between analytically and experimentally derived mathematical models. Before such a comparison may be considered meaningful, however, it is necessary to make "orthogonality checks" of the measured modes. These checks require a detailed knowledge of the actual mass distribution of the spacecraft. Since this knowledge was not available in requisite detail, a correlative objective has been the experimental determination of weights, center-of-gravity locations, moments of inertia, and, in some instances, products of inertia of the major items of simulated equipment on the spacecraft.

A closely related objective has been the direct measurement of those structural transfer functions that relate to closed-loop autopilot stability, i. e., the motional inputs to the flight-control gyros and accelerometer for sinusoidal forces and moments applied through the vernier engines.

EXPERIMENTAL EFFORT

The experimental portions of the work have been completed, and the test data are undergoing analysis and interpretation.

Mass-Property Measurements

The mass-property measurements, extending over a period of about 3 mo, have accounted for about 85% of the weight of the spacecraft in a manner compatible with the requirements for the orthogonality checks. The residual data, largely applying to the distributed masses of the structural spaceframe, equipment support structure, and electrical cabling, have been obtained from Hughes Aircraft Company.

Boost Configuration

Modal vibration surveys for the boost configuration were conducted with the spacecraft mounted on the upper section of the Centaur adapter structure (Fig. 1). A ten-channel vibration excitation system was employed, with all ten channels required to excite certain modes. Fourteen natural modes were identified and surveyed in the frequency range below 30 Hz.

Lunar Touchdown Configuration

For transfer function measurements in a lunar touchdown configuration, the spacecraft was suspended in a manner providing very low frequencies (less than 0.3 Hz) in all six rigid body degrees of freedom. Figure 2 shows this test setup with electrodynamic shakers attached to the simulated vernier engines. Under sinusoidal excitations, outputs of three rate gyros and a longitudinal accelerometer were recorded on magnetic tape for subsequent determination of frequency response data (amplitude ratios and phase angles).

Modal surveys for the chosen touchdown configuration revealed thirteen natural modes below 30 Hz. Twelve of these were surveyed in detail.

PROGRESS

Test data for both configurations are being continuously evaluated. The publication of the report describing this test program has been delayed pending the completion of the data analysis. Documentation describing the comparison between predicted and measured modes will be funded by the Surveyor Project.

No further effort under this work unit is contemplated.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

1. Test Program Report.

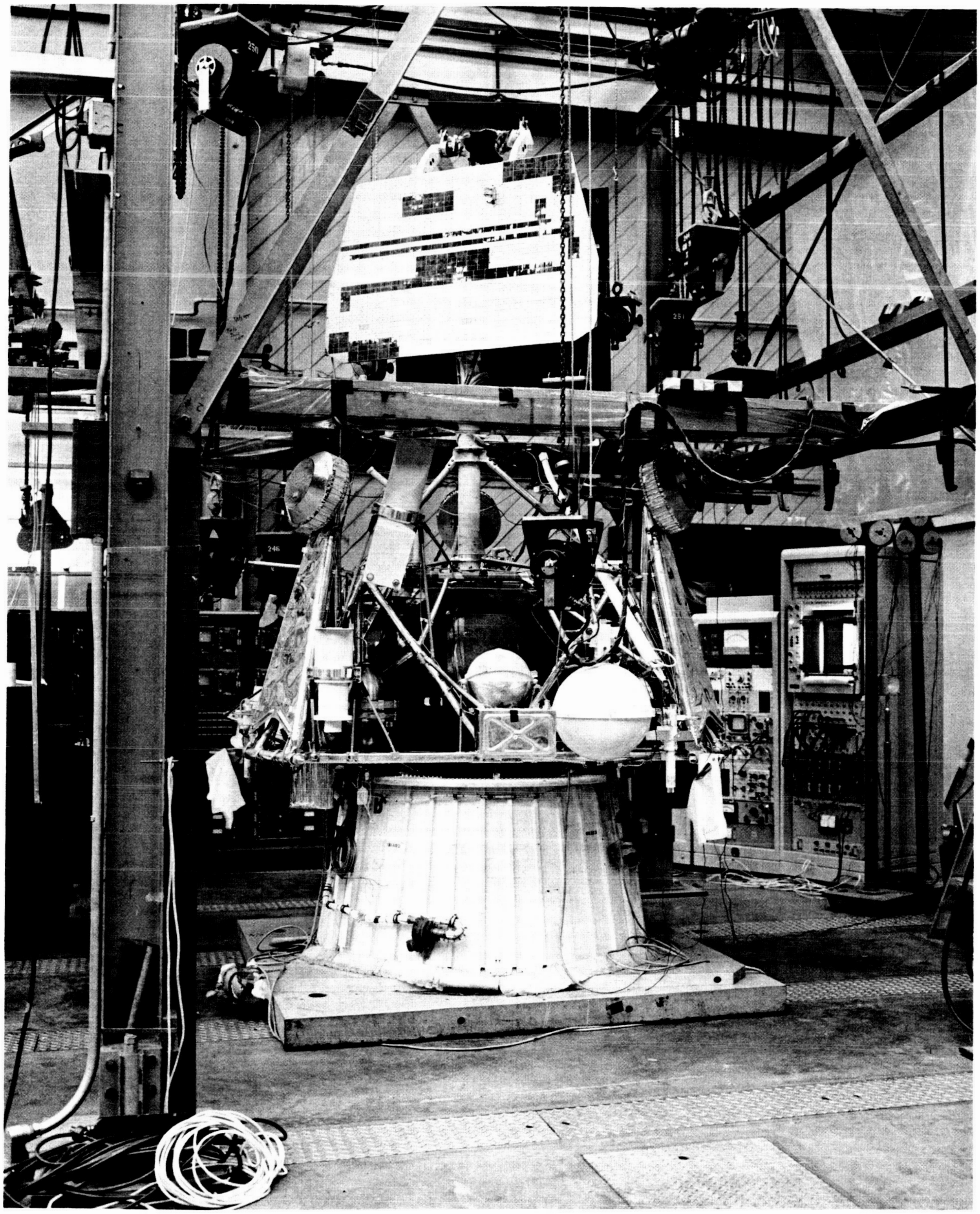


Fig. 1. Test setup for modal surveys of the S-9 spacecraft in the launch configuration

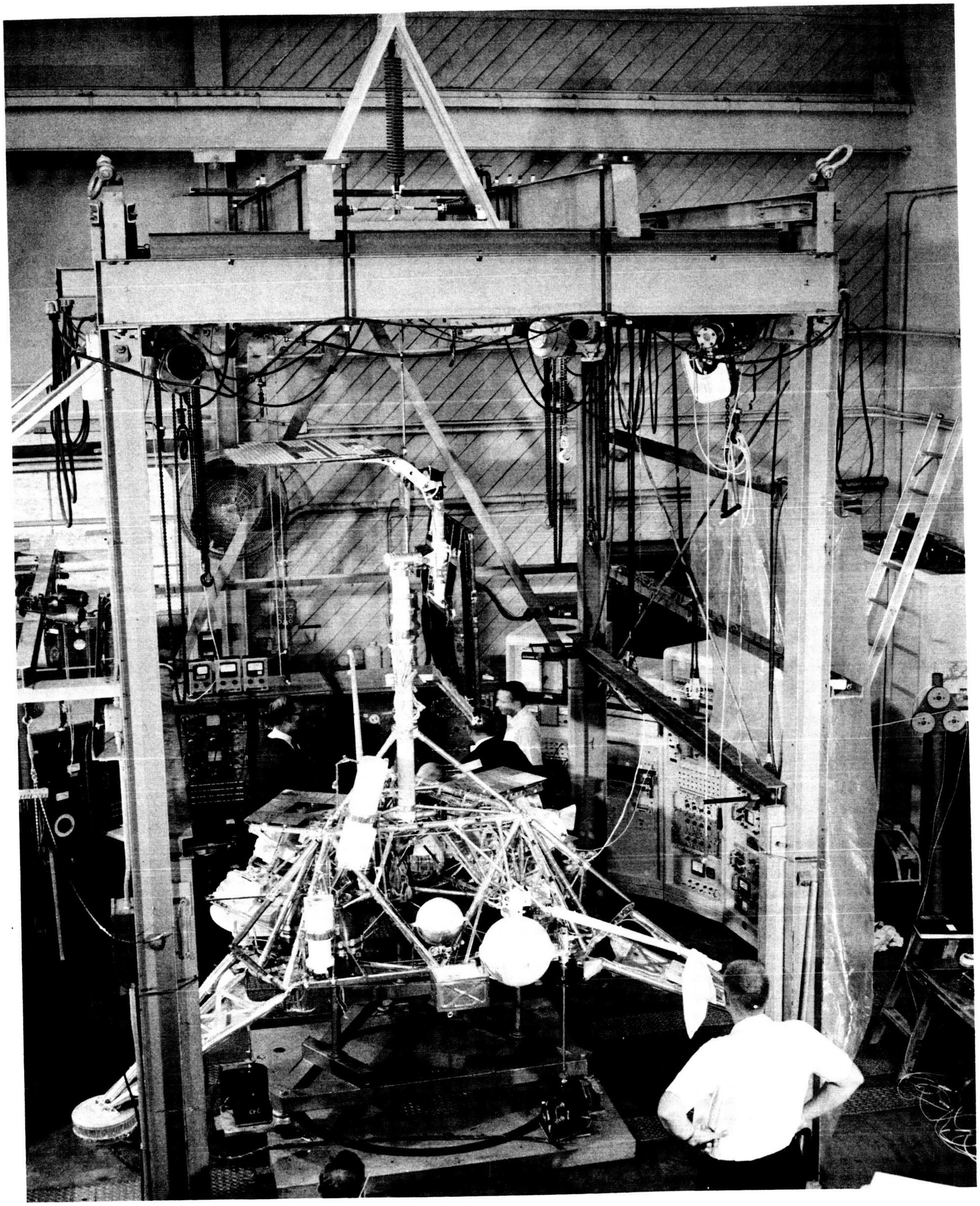


Fig. 2. S-9 spacecraft suspended in touchdown configuration for structural transfer function measurements

LUNAR AND PLANETARY HORIZON SCANNER

NASA Work Unit 186-68-02-04-55
JPL 384-60501-2-3440
J. M. McLauchlan

OBJECTIVE

The objective of the Lunar and Planetary Horizon Scanner (LPHS) Program is the development of a long-life infrared horizon sensor with no moving parts. This sensor will be useful on Voyager-type missions for providing information regarding the direction of the local vertical of a planet from an orbiting spacecraft. The development is being accomplished with the aid of an industrial contractor (Barnes Engineering Co.) for design and fabrication; JPL is providing support in various design areas, as well as detailed testing and evaluation.

DESIGN AND FABRICATION

During the current reporting period the electronic Design Verification Unit (DVU) of the scanning head was fabricated by a subcontractor (Sippican) and tested by the contractor. Some rework was necessary, and after completion and retesting, approval was given for the subcontractor to start fabrication of the prototype head electronics.

A special integrated circuit used in the common electronics was initially packaged in a TI case by the manufacturer, Siliconix. There were problems in sealing this case, and it was necessary to change to another vendor's case, which in turn necessitated a redesign of the common electronics packaging.

The special fixture used to hold the head commutator integrated circuits for testing by the test console were reworked and subsequently redesigned by the vendor (Azimuth Electronics).

The foregoing problems, while not of a serious technical nature, have considerably delayed completion of the fabrication of the engineering prototype LPHS. To conserve costs while these subcontractor and vendor problems are resolved the contractor has curtailed his in-house activities to entail only the director of the subcontractor and vendors. In addition the estimated costs of this phase (fabrication testing and evaluation of a single axis LPHS) has increased from the currently funded $124,000 to an estimated $164,000.

PLANNED ENGINEERING MODEL TESTING

Delivery of the engineering model LPHS to JPL is now planned for the second quarter of FY 1968, however, inasmuch as this task will not be continued in FY 1968, no additional effort will be expended beyond the end of FY 1967.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

1. Contractor final technical report on the LPHS program, November 1968.

FLIGHT COMPUTERS AND SEQUENCERS ADVANCED DEVELOPMENT

NASA Work Unit 186-68-02-08-55
JPL 384-63701-2-3410

G. R. Hansen, Jr.

OBJECTIVE

The continued objective of this work unit has been the development of advanced Central Computer and Sequencer (CC&S) Subsystems. The plan for the next period, directed toward meeting this objective, is to develop a specific CC&S design and to construct a prototype unit that can be environmentally tested and evaluated. The CC&S requirements considered are those defined by a planetary capsule system. Included in the capsule requirements are the sterilization and landing impact shock environments. It will be the design goal of this work unit to meet these requirements.

PROGRESS

The principal effort on this work unit has been in direct support of the Mariner Mars 1969 project in two areas. A design handbook has been created which codifies the design analysis, component specification, and electrical schematics. This effort will aid in the future application of integrated circuits in other applications.

An engineering model of a 3838-bit core storage unit (see Fig. 1) was developed and furnished to the Mariner Mars 1969 for inclusion in the CC&S. This memory employs a novel bidirectional current steering switch. The memory is a direct outgrowth of technology developed under NASA Work Unit 125-17-04-01-55. The memory has a capacity of 128 words of 22 bits each. One additional work of 22 bits is also provided which is available in the same time without addressing. The memory operation is bit serial within a work. A novel technique utilizing bipolar current steering switches to obtain read-write current pulses on the same wire was invented during this development.

Programming of the common trigonometric and square root subroutines has been accomplished on the ICL computer. These routines are necessary for solution of the approach guidance experiment. The trigonometric routines are accurate to 20 arc seconds.

The Lander Sequencer and Time (LST) functional requirements of the Capsule System Advanced Development (CSAD) have been documented. In addition a functional requirement document for the Entry Sequencer and Timer and Entry Timer has been prepared. A preliminary design has been determined for the LST and construction of a breadboard has started. A major portion of the engineering model of the LST is planned for completion in the next 6 mo.

The hybrid integrated circuitry equipment (previously acquired under this work unit) has been physically transferred to a centralized facility under control of Division 35 (Engineering Mechanics) to better serve the entire Laboratory.

APPROACH

Capsule CC&S requirements differ significantly from those for bus systems. Power requirements are much more stringent and the physical environment more severe because of the sterilization and landing shock capability. To achieve minimum power, it is necessary to focus attention to the most basic part of any sequencer, namely, the countdown chain. The lowest frequency flightworthy crystal oscillator is in the supersonic region (19 kHz). Therefore a lengthy countdown chain is required, especially for landed systems. One area which will be investigated is the feasibility of developing a low-frequency oscillator with power requirements comparable to battery-powered electric clock movements. The first attempt will be to develop an oscillator using frequency selective RC networks together with linear amplifiers composed of metal oxide semiconductors. The second area to be developed is a minimal power counting chain probably using self-latching semiconductors such as the silicon controlled switch.

A continuing effort will be the exercising of the "breadboard" Inhibit Core Logic Computer developed under NASA Work Unit 125-17-04-01-55. In particular, the computer will be programmed to accomplish the approach guidance experiment (NASA Work Unit 186-68-02-21-55) computations required for the Mariner Mars 1969 mission. The equations will be furnished by the Guidance and Control Analysis and Integration Section. Present plans call for the computer to be utilized during the operations phase of the mission as part of the experiment.

PUBLICATIONS

None.

ANTICIPATED PUBLICATIONS

None.

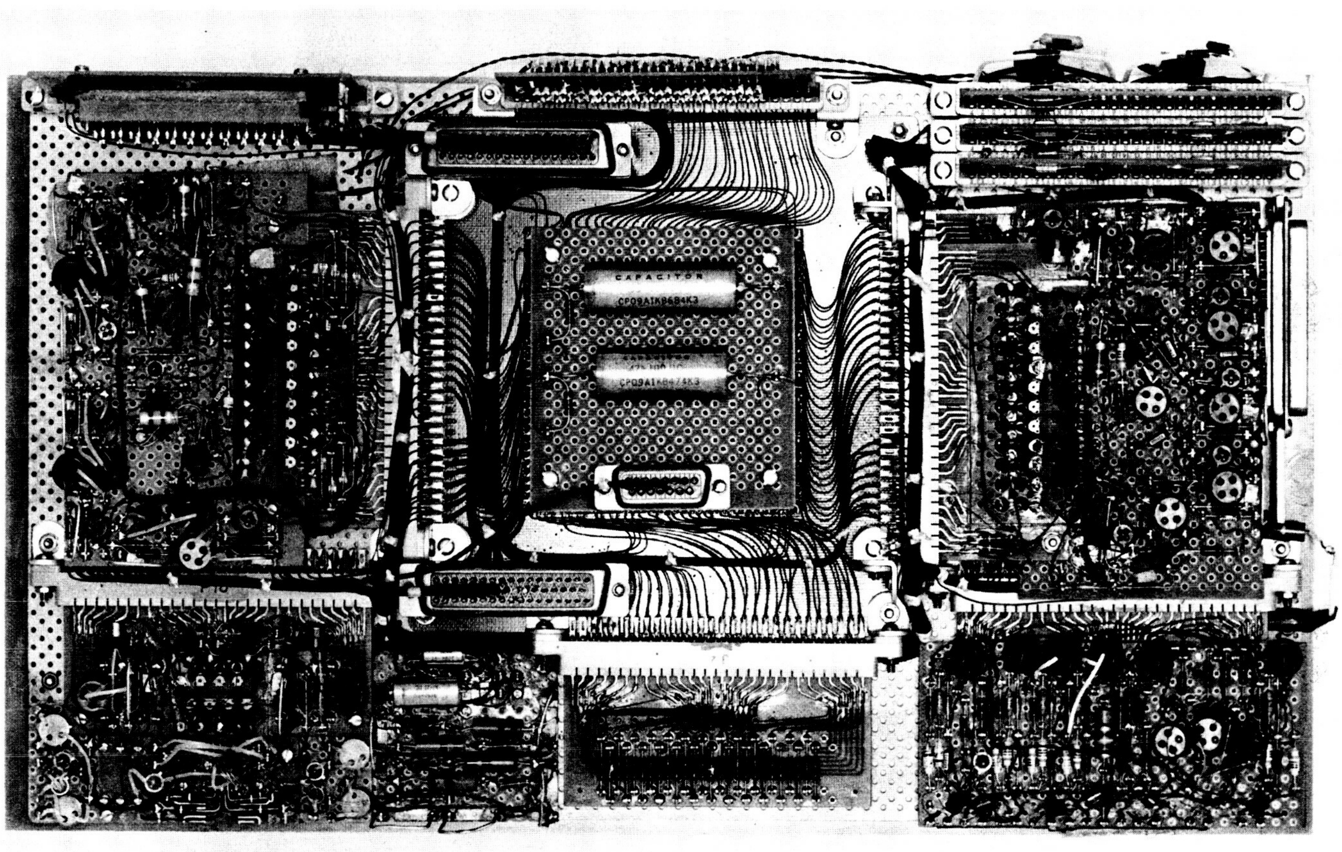


Fig. 1. Mariner Mars 1969 CC & S memory breadboard

ADVANCED SCAN PLATFORM
NASA Work Unit 186-68-02-09-55
JPL 384-61901-2-3440
H. Horiuchi

OBJECTIVE

The long-range objective is to demonstrate the feasibility of a scan platform that is optimized to accommodate a multiplicity of science requirements. The optimization will be effected in terms of improving system design such that scanning programs and information storage may be accomplished in a more versatile and reliable manner than in present systems. In addition, optimization will be considered in terms of pointing accuracy, velocity jitter, transient response, and structural characteristics. In this fiscal year an emphasis was placed on investigation of the feasibility of a digital horizon scanner, transient characteristics, and structural dynamics of the scan platform.

SUMMARY

The horizon scanner (being developed under NASA Work Unit 186-68-02-04-55) and its integration into scan control system has been studied.

The control system analysis with emphasis on low jitters, transient characteristics, boom, and spacecraft dynamics has been performed. A breadboard model, including a simulated scanner and boom dynamics, was built and used to study the system parameter optimization. The parameter optimization study was conducted further by digital computer simulation using DSL/90 program.

FUTURE PLANS

The advanced development program will not be continued due to redistribution of funds and manpower.

PUBLICATIONS DURING REPORT PERIOD

<u>JPL SPS Article</u>

1. Horiuchi, H., "Advanced Scan Platform," SPS 37-44, Vol. IV.

ANTICIPATED PUBLICATIONS

None.

SPACECRAFT GUIDANCE RADARS
NASA Work Unit 186-68-02-14-55
JPL 384-61001-2-3360
R. L. Horttor

OBJECTIVE

The primary long-range objective of this work unit is to make available the necessary technology, in the form of Spacecraft Guidance Radar hardware for a soft landing of a life determining Mars Capsule in 1975. A secondary long-range objective is to classify the needs for Guidance Radar for Future Missions. The short-range objective of this work unit is to determine constraints, functional requirements, and alternate mechanizations for Mars Capsule Guidance Radar through studies and analysis of: (1) pulse radar altimeters, (2) continuous wave radar altimeters, (3) pulse radar velocity sensors, (4) continuous wave doppler sensors, and (5) altitude marking radars.

ACTIVITIES

While this task is general in nature, it has rather pointedly been directed toward the preparation of a Mars Lander in 1975. The short-range objectives of determining constraints, functional requirements, and alternate mechanizations were largely satisfied in the first half of FY 1967 in conjunction with Voyager studies culminating in VPE-14 (a JPL Voyager proposal to NASA). Subsequent decisions concerning the management responsibilities of the Voyager mission places no need for JPL to supply radar technology for that mission. With that decision, in-process analysis was completed, and applicability of the radar task for other needs was sought. The conclusion reached was that there is no need in the foreseeable future for guidance radar at JPL. Other applications of radars for metrics and imagery were sought. Since some work at JPL in these areas is going on (NASA Work Units 185-39-05-01-55, 185-39-05-01-55, 185-41-21-02-55, 190-42-20-16-55, 150-22-14-05-55, and 150-22-12-11-55), the investigation was largely restricted to techniques which could use current telecommunication hardware elements and techniques (ranging transponders). While this is feasible and offers some advantage, there is as yet no strong reason for continuing this task. Effort will continue through at least part of the first quarter of FY 1968 until a firm decision can be made.

Guidance Radar Performance Analysis

The objective of this task is to evaluate various techniques for providing the information required from the Guidance Radar. Topics of interest include beam configuration, search and acquisition, parameter estimation, modulation, detection, and tracking techniques. Hardware implications are to be a consideration, as are the influences of surface effects on the return signals.

The work during the reporting period investigated several properties of a radar beam configuration suitable for a Mars retro lander. Earlier work had determined three main functional requirements of the radar system. These were (1) an altitude signal, or mark, to start the powered descent, (2) range to the surface along the

vehicle roll axis, and (3) the three components of the vehicle velocity vector. For these purposes, the radar performance could be analyzed in terms of the quality of the radar output data. The variances are functions of the radar beam look angle from the vehicle roll axis. Some details of the results are listed below:

(1) Altitude Marking Accuracy. This function of the radar is most critical since the entire powered descent depends on a dependable starting signal. The simplest method is to generate a signal when the slant range reaches a certain value. However, because of the low trajectory angles (30 to 40 deg above the horizontal) small changes in the vehicle attitude could produce large variations in the actual attitude at which the signal would be generated. The sensitivity of the marking altitude to vehicle attitude was reduced by deriving the mark from whichever of the four outward pointing beams first encountered the critical range value. The data in Ref. 1 shows the increased marking accuracy resulting from this scheme. However, the vehicle must not have much roll rate for the radar to work in this mode. Just how much has not yet been determined.

(2) Slant Range Estimation Bias Error. Slant range may be measured directly by means of a beam along the roll axis, or by averaging the range measurements of the outer four beams. The latter technique introduces a measurement bias which depends on the beam look angle and the trajectory angle. Reference 2 reports the severity of these bias errors.

(3) Variances of Range and Velocity Estimates. The variances of the range and velocity estimates were derived for several estimation techniques using three, four, or five beams. In each case, the results were heavily dependent on the radar beam look angles. An interesting result was the greatly reduced variance of the range estimate permitted by averaging together the noise contributions of the four outer beams. These and other results are reported in Ref. 3.

The work described above can greatly assist the design of a guidance radar for a Mars retro lander. Knowledge of the Martian atmosphere would allow the design to accommodate a particular trajectory. The beam look angle could then be chosen for maximum marking accuracy at the desired altitude. The slant range bias error and the range and velocity variances would also be known.

Application of Synthetic Aperture Radars to Spacecraft

The objective of this task is to study and apply radar techniques to needs of various spacecraft of space missions. At present, the effort is to apply mapping radar techniques to suitable missions. Various lunar and planetary operating modes are being considered.

Work in Progress

This effort is part of a more general redirection of the radar program. Work will include the following:

(1) Exploration of currently applied techniques for imagery of moon and planets.

(2) Exploration of currently available radar techniques for space use.

So far the synthetic aperture technique looks promising when mounted on an orbiting spacecraft. The receiving and data processing systems may be on the spacecraft or on ground, depending on several other considerations such as, weight, size, power consumption, reliability, etc.

To date, the work has considered a bistatic synthetic aperture radar with the transmitter on board a spacecraft orbiting the moon and a receiver on earth. A computer program has been written which calculates the effective aperture pattern. This will be useful in evaluating the system resolution. Basic feasibility may be assessed by these results and a signal strength analysis.

An additional idea is an attempt to use RF holography to create a surface map. There has not been sufficient work to draw strong conclusions.

To support the above activity, the "Thirteenth Annual Tri-Service Radar Symposium" in Seattle, Washington was attended.

Hardware Studies

The plan to obtain manpower support by contract to augment the radar task with hardware capability was carried out with a contract to Sass-Widders for $20,000. With the change of needs, this contract was subsequently cancelled.

REFERENCES

See Publications below.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Horttor, R. L., "Probability Distribution for Guidance Radar Beam Surface Incidence Angles," SPS 37-43, Vol. IV.

2. Horttor, R. L., "Spacecraft Guidance Radar Beam Configuration Performance I," SPS 37-44, Vol. IV.

3. Horttor, R. L., "Spacecraft Guidance Radar Beam Configuration Performance II," SPS-37-45, Vol. IV.

ANTICIPATED PUBLICATIONS

None.

CENTRAL PROCESSOR SPACECRAFT CONTROL
NASA Work Unit 186-68-02-17-55
JPL 384-68501-2-3410
J. J. Wedel, Jr.

OBJECTIVE

The objective of this work unit is to perform a detailed study of methods for centralizing the processes presently used in spacecraft control functions. It is expected that many of them can be accomplished with a small digital computer similar to that already used for the computing and sequencing function. If factors such as reliability, power, weight, and growth potential are favorable, conversion to a centralized digital processor would be desirable. Another objective of this study is to reveal where on-board digital computing or data processing techniques could improve the performance of the spacecraft guidance and control subsystems.

PROGRESS

The initial work has concentrated on the present Mariner Mars 1969 guidance and control subsystems inasmuch as these are well defined and offer the possibility of making detailed tradeoff studies. The desirability of using digital techniques appears to hinge chiefly on developing and using digital sensors instead of the analog sensors in use today. Without their use, analog-digital converters are required with a consequent increase in weight and reduction in reliability. The development of digital sensors does not appear to be a formidable problem and at least one solar sensor is available at present.

Although it is recognized that digital techniques are generally more accurate and reliable than analog ones, there does not exist a common yardstick to compare them. An attempt will be made to develop such a yardstick to compare reliabilities. Since the ability to introduce block redundancy is another advantage of a digital system, an attempt will be made to introduce this into the control system. It is intended that the control loop for the Mariner Mars 1969 will be designed using digital implementation. This design will be compared to the present analog loop.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

OPTICAL SENSORS TECHNIQUES AND COMPONENTS

NASA Work Unit 186-68-02-19-55
JPL 384-64601-2-3440
J. M. McLauchlan
L. F. Schmidt

OBJECTIVE

The objectives of this program consist of the development of the technology and components common to the many types of optical sensors used for attitude control guidance. Included are the following activities: (1) continuation of lens design program improvement, (2) optical system design and evaluation techniques, (3) improved performance of image dissectors, and (4) continuation of development of a program for the automatic design of electron optical systems.

IMAGE TUBE DEVELOPMENT

The objective of this work is continued improvement of the basic all-electrostatic image dissector (ID) tube used in the Canopus star sensors on the Mariner IV mission. This work is being carried out by CBS Laboratories. Improvements of the tube characteristics are required for high-performance star sensor, approach guidance planet sensor, and other potential applications.

The ID tube improvement effort has been combined with the high-temperature photocathode task (NASA Work Unit 186-58-02-02-55) under one contract for increased efficiency. The advantage is that the same tubes built for studying ID electrostatic improvements can also be used to determine the high-temperature properties of the photocathode.

Tests conducted on ID tubes fabricated during this period indicate that image distortion as previously measured, does not exist. The problem was discovered by CBS to be due to faulty instrumentation. The major current emphasis therefore lies in the improvement of resolution and in increasing the deflection sensitivity of the ID tube. The empirical approach by CBS to improve resolution has resulted in no significant improvement. It has indicated that the ID is not very resolution-sensitive to small changes in the electrode geometry in their present configurations. New deflection structures have been designed and fabricated for the ID. The subsequent testing of these structures in the ID will indicate if deflection sensitivity can be improved with no loss in resolution.

Experimental photomultiplier (PM) tubes built during this period have indicated that the bialkali photocathode, being developed to withstand sterilization temperatures, is feasible. A problem is that, although the PM can be made to go through a sterilization cycle with small changes in sensitivity (approximately 10%), initial sensitivity is low (about 25 μA/lumen) and photocathode uniformity varies considerably.

ELECTRON OPTICAL COMPUTER DESIGN PROGRAM

The objective of this activity is to develop a computer program for use in the design of electrostatic electron optical imaging systems. This is an alternate approach to the quasianalytical and empirical means presently employed in this type of design.

The initial approach was one in which, given the geometry of the electrodes, the inter electrode capacities were computed. Then given the potentials applied to the electrodes, incremental charge densities were computed for symmetrical areas of the electrodes. Finally these charge densities were integrated to obtain potentials at selected internal points in the imaging system. After the internal field potentials are determined, the trajectories of electrons with various initial conditions are determined in order to establish the imaging quality. A major problem encountered in trying to implement this approach in a program for use on the IBM 7094 is that the computations take too much machine time. This basic approach has been recently temporarily abandoned in favor of another method.

An existing computer program, which was developed (under the sponsorship of Langley Research Center) at Stanford University by Dr. Hamza, is now being considered. This program was developed to calculate the trajectories of ions in electrostatic ion propulsion systems. With modifications it appears that the program will be suitable for our application.

OPTICAL LENS DESIGN PROGRAM

The computer program has now been reprogrammed completely into Fortran IV language and has been tested for proper operation. The program has been made available to Flight Research Center and Manned Spacecraft Center (inquiry has also recently been received from MSFC).

An additional option has been built into the program. This option provides a two-dimensional plot of the lens design configuration. This eliminates the need for the designer to draw the lens configuration by hand after each design run in order to determine if the design is compatible with the space requirements and is producible.

The program has been used during this period to complete the design of the optical system for the Mariner Mars 1969 Canopus star tracker.

FUTURE ACTIVITIES

The presently contracted work at CBS Laboratories will be completed. A new effort to further improve the image dissector will be initiated. The additional goals will be design changes to achieve: better manufacturability, increase manufacturing yield, and a design that will be more suitable for packaging for space instrument environment.

The effort to develop an electro-optical computer program will continue with the major emphasis on modification of the existing ion trajectory program.

The mathematical methods used in the lens design program will be studied to improve on the running time of the program when designing.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

JPL Technical Report

1. Schmidt, L., and Casad, T.A., Automatic Design of Optical Systems by Means of an IBM Digital Computer Employing the IBJOB Monitor, TR 32-790, August 15, 1967. (This technical report pertains to the machine language version only, subsequent reports are planned to cover the Fortran IV version.)

GUIDANCE AND CONTROL SUBSYSTEMS INTEGRATION FOR FUTURE MISSIONS

NASA Work Unit 186-68-02-21-55
JPL 384-65201-1-3430

W. G. Breckenridge

OBJECTIVE

The long-range objectives of this work unit are (1) to study the interactions among guidance, attitude control, computing and sequencing, and power subsystems for lunar and planetary spacecraft, and (2) to utilize the information obtained for the development of coordinated, compatible guidance and control subsystem configurations. Another objective of this work unit is to develop analytical techniques with common application among several subsystems.

APPROACH GUIDANCE

The effort in this work unit for the last half of FY 1967 has been on the "Spacecraft-Based Optical Approach Guidance Evaluation" study, JPL Contract 951936. During this period, the procurement process from issue of the Request for Proposals through contract award was completed. The selected contractor is TRW Systems. Work started on the contract on June 1, 1967.

Phase I of this contract is of 6-mo duration, to develop a mathematical model and digital computer simulation of those aspects of the spacecraft that affect the taking of optical measurements of the direction to a target planet. The simulation will include: (1) trajectory geometry (based on data from existing trajectory programs), (2) spacecraft attitude control dynamics, (3) sun, star, and planet sensor performance including error source simulation, and (4) telemetry subsystem commutation and quantization of the data.

The output of the program will be a simulation of the data stream from the spacecraft. This data may be used for: (1) input to data processing programs for the evaluation of the computational procedures when subjected to data noise of a type that cannot be modeled for analytic evaluation, (2) verification and checkout of software developed for the Mariner Mars 1969 Optical Approach Guidance Technology Development and Flight Feasibility Demonstration, or (3) verification and checkout of orbit determination software to be prepared for the Inhibit-Core Logic Computer breadboard developed at JPL under NASA Work Unit 125-17-04-01-55.

In the first half of FY 1968 the effort in this work unit will be the monitoring of the study contract and preparation for phase II of the contract, which will add orbit determination data processing to the simulation program. The design of the magnetic logic computer program for orbit determination will be started.

PUBLICATIONS DURING REPORT PERIOD

Contractor Reports

1. Phase I Implementation Plan for the Study Program of Spacecraft-Based Optical Approach Guidance System, TRW Systems, Interoffice Correspondence 3412.9-126, June 13, 1967 (JPL Contract 951936).

ANTICIPATED PUBLICATIONS

Contractor Reports, Interim and Final

1. Monthly Technical Progress Reports.
2. Mathematical Model Documentation.
3. Computer Program Definition Documentation.
4. Prototype Computer Program Documentation.
5. Final Report (JPL Contract 951936).

DEVELOPMENT OF ACTUATOR PROCESSES AND MEASURING TECHNIQUES
NASA Work Unit 186-68-02-22-55
JPL 384-64701-2-3440
John Ferrera

OBJECTIVE

The objective of this work unit for the second half of FY 1967 is divided into four subtasks:

(1) Continue to establish the interrelationship of particulate contamination and present concepts of expected life and/or reliability pertaining to electromechanical devices. This subtask has been broken down into a new task unit for FY 1968 to comply with NASA direction: "Particulate Contamination Control Study," NASA Work Unit 186-68-02-37-55, JPL 384-70701-2-3440. The objectives of this task are best detailed in the FY 1968 1122 backup sheet for this new task and in the semiannual report for the first half of FY 1967 (JPL TM 33-322) under NASA Work Unit 186-68-02-22-55.

(2) Finalize the Quantitative Leak Test Design Guide. This work is being done under JPL Contract 951763 ($28, 740) with the General Electric Company of Schenectady, New York. The intent of this contract is to improve the technique of leakage determination of large, complex devices such as assembled spacecraft. A description of the procedure under investigation is detailed in the semiannual report for the first half of FY 1967 (JPL TM 33-322).

(3) Continue the establishment of thrust, thrust transient, and impulse measuring techniques for thrusters in the milli- and micro-pound range. This task was deleted from "Millipound Attitude Control Actuator Development," NASA Work Unit 186-68-02-26-55, JPL 384-66801-2-3440 and added to "Development of Actuator Processes and Measuring Techniques," on January 1, 1967 for reasons detailed in the FY 1122 backup sheet for "Millipound Attitude Control Actuator Development," NASA Work Unit 186-68-02-26-55. A more detailed description of the objective and approach to this subtask can be found in the FY 1968 and FY 1967 1122 backup sheet for "Development of Actuator Processes and Measuring Techniques" and in the last semiannual report for "Millipound Attitude Control Actuator Development," NASA Work Unit 186-68-02-26-55.

(4) Develop the capability necessary for testing the two SPET motors delivered under JPL Contract 951591 with the General Electric Company. The SPET motors were procured under "Millipound Attitude Control Actuator Development," NASA Work Unit 186-68-02-26-55, JPL 384-66801-2-3440. A more detailed description of the SPET concept can be found in the last semiannual report for MACAD.

PARTICULATE CONTAMINATION

A set of graphs and/or equations which relate contamination by hard and soft particles of specified sizes and concentrations to life expectancy and/or reliability is required for such mechanical and electromechanical devices as bearings, gears, solenoids, valves, motor brushes, filters, regulators, etc. Information from this study will be used as an aid in defining design, cleaning, assembly, and handling techniques and establishing life expectancy for spacecraft hardware built by and for JPL. This effort will be expanded in FY 1968 to include required changes in clean-room activity resulting from AD programs. A JPL literature search (751) entitled "Effects of Particulate Contamination on Reliability and/or Life Expectancy for Typical Mechanical and Electromechanical Devices" was conducted in this report period to determine what work has been done in this area. An initial review of this search indicates that more detailed information on mechanical, rather than electrical components is needed. Much of the information collected in the search was either too specific, incomplete, outdated, or irrelevant to provide the required information needed for the graphs and/or equations mentioned above. A rough draft of a letter of interest to be sent out by July 1, 1967, to determine those companies interested in, and capable of, conducting a study on the subject has been completed. This study, utilizing information contained in a more detailed examination of the articles in the search and phone and written conversations, will gather such information as, but not limited to, that listed below:

(1) A collection of reliability theories pertaining to particulate contamination and suggestions as to those most applicable to the above.

(2) Collection of data on particle-size sensitivity of various mechanical components where available and indications where more data is necessary.

(3) Compilation of as much data as is available and suggestions as to what further data is needed and how it can best be obtained to develop the mentioned graphs and equations.

(4) Indicate areas where published reliability figures should be updated to take into account hardware designed to aerospace specifications.

The results of this study will better enable the future allocation of funds to the areas needing further analytical and experimental investigation and/or data collection. An RFP will be written for a study contract in the first period of FY 1968. Target date for letting a contract is January 1, 1968.

BAG-LEAK-TEST TECHNIQUE AND DESIGN GUIDE

The test technique is described in detail in the last semiannual report for this work unit. JPL Contract 951763 with General Electric Company of Schenectady, New York for $28,740 started on December 28, 1966. The contract is intended to determine leakage characteristics, correlation between helium and nitrogen leakage through the same path, optimum bag material, and to design a guide outlining the procedure and describing how to reduce data to meaningful engineering measurements. The calibrator, bag, and rough copy of the final report and design guide were delivered to JPL on May 16, 1967. As pointed out in the rough draft of the final report, the accuracy of the results obtainable by the developed method will vary

depending on enclosure volume, test leak rate, and leak detector sensitivity. The speed of the test will also vary in accordance with these parameters. In one recent test a leak rate of 16 cc/h was predicted with 2% accuracy in a period of 6 h with an enclosure volume of 195 ft^3. This is an improvement over the 15% accuracy obtained prior to the contract. Increased accuracy plus the design guide were the two major objectives of the contract. The final copy of the final report and design guide will be received by August 1, 1967. Monthly progress reports were also received. An acceptance test will be run to check the design guide and calibrator beginning June 18, 1967.

THRUST AND IMPULSE MEASURING TECHNIQUES

A wider variety of thrust levels and more exacting control of given thrust levels is envisioned as required for future JPL unmanned planetary orbiting, flyby, and landed programs in the design, development, and testing of torquing devices for attitude control systems. The ability to measure thrust levels from 10^{-1} to 10^{-6} lb in time intervals down to 10^{-3} on a per pulse basis will provide the capability for in-house evaluation of the relative merits of prototype thrusters (obtained from in-house or through contract development) which are proposed to satisfy specific mission requirements. The progress in this area was reported in the semiannual report for the first half of FY 1967 under "Millipound Attitude Control Actuator Development," NASA Work Unit 186-68-02-26-55. Since that report the following progress has been made. Problem areas arose in the strain gage approach toward implementing the cantilever beam. These problems and some solutions as well as a calibration procedure are detailed in SPS 37-44, Vol. IV, "Calibration Procedure Used in the Attitude Control Nozzle Thrust Measuring Techniques." As indicated in this article a light source is now being used to replace the strain gages. This has solved most of the problems. The cantilever is presently being calibrated. If no further problems are encountered, a test program will begin in July. Mariner-type nozzles of differing geometries are now being fabricated in-house to be used with this test program to verify the steady state computer results. The cantilever beam approach has the capability of measuring millipound thrust levels with response on the order of a few milliseconds. In the next six-month period work will begin on providing the instrumentation to measure thrust-time profiles. The steady state thrust computer program outlined in the semiannual report for the first half of FY 1967 (MACAD, NASA Work Unit 186-68-02-26-55) and in the 1122 backup sheet for FY 1967 and FY 1968 for "Development of Actuator Processes and Measuring Techniques," NASA Work Unit 186-68-02-22-55, has been completed and a rough draft of the final report on the results of the steady state thrust computer program has been written. The final report will be published in July. Work on the transient computer thrust analysis will begin in July.

SOLID PROPELLANT ELECTRICAL THRUSTER (SPET) TESTING

Two SPET motors have been procured from General Electric (JPL Contract 951591) under "Millipound Attitude Control Actuator Development," NASA Work Unit 186-68-02-26-55. A description of these motors can be found in the last two semiannual reports under the MACAD number. These motors will be tested under this NASA Work Unit 186-68-02-22-55 task as outlined in the FY 1968 1122 backup sheet. A vacuum station for this testing was ordered on February 17, 1967 and received on May 3, 1967. It is now installed and operating. The necessary power

supplies, bell jar collar, electrical feedthroughs, and measuring equipment have been ordered and will arrive before July 4, 1967. Of the two responses to an RFP for a torsion pendulum to measure thrust in the 10^{-6}-lb range, General Electric has been selected and the purchase order is currently being signed off. A 3-wk delivery has been promised. No delays are anticipated. The torsion pendulum will then be installed in the vacuum station along with the necessary electrical equipment. Testing using the torsion pendulum is scheduled to begin on August 1, 1967. Testing has been done to become familiar with the operation of the SPET motors. Reports on SPET development will be listed under the semiannual report for MACAD (NASA Work Unit 186-68-02-26-55).

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Ferrera, J. D., and McKown, P. M., "A Parametric Analysis for Steady State Performance of Attitude-Control Thrusters," SPS 37-42, Vol. IV.

2. Ferrera, J. D., "Calibration Procedure Used in the Attitude Control Nozzle Thrust Measuring Technique," SPS 37-44, Vol. IV.

ANTICIPATED PUBLICATIONS

1. Final Report and Quantitative Leak Test Design Guide, General Electric, JPL Contract 951763.

2. Technical Report on Steady State Thrust Computer Analysis.

3. SPS Article on Experimental Thrust Analysis.

4. Technical Report and/or SPS Article on Computer Program for Transient Thruster Performance.

5. SPS Report on Results of SPET Testing.

APPROACH GUIDANCE SUBSYSTEM DEVELOPMENT

NASA Work Unit 186-68-02-23-55*
JPL 384-66101-2-3440
F. R. Chamberlain

OBJECTIVES

The long-range objective of the Approach Guidance System Development is to increase the guidance accuracy capability in the approach phase of planet encounter trajectories by means of optical measurements.

The immediate objective in development of an Approach Guidance System is the inclusion of an experimental subsystem on the Mariner Mars 1969 mission to Mars, in which an Approach Guidance Subsystem (A/G) will measure optical pointing angles to Mars and to the sun. Data from the A/G and from the Canopus sensor will be telemetered to ground, where processing of data will be employed both in trajectory prediction and in evaluation of hardware performance. No maneuver will be performed in the Mariner Mars 1969 experiments; postencounter trajectory data will be used to evaluate the accuracy of prediction achieved.

PROGRESS

A Phase I development and prototype fabrication effort has reached the completion of detailed design. Breadboard performance has demonstrated capability of the basic mechanization to acquire and track a planet. Precision simulators and other ground equipment are fully designed, and fabrication is nearly complete. Procurement and screening of parts for flight hardware is in progress, and documentation is being upgraded in anticipation of a design freeze in August 1967 when fabrication of flight hardware begins. Cost proposals for the phase II flight hardware fabrication and testing have been received. The procurement cycle for this phase II effort will dovetail adequately with the phase I design, and with the flight parts procurement and screening effort. An overall assessment of progress to date is as follows: original contract (began October 1966) called for completion of the phase I effort in October 1967; an attempt was made to compress this program by 4 mo to meet project schedules, but approximately 6 wks of lost time at the beginning of the effort has limited program compression to an effective 2 1/2 mo. Current schedules do not project slippage of flight hardware delivery, but the schedule for the proof test model (PTM), which is to be delivered January 16, 1968, is extremely tight.

PLANNED ACTIVITIES

Fabrication and testing of flight hardware will begin in August 1967, under an increase in scope to the basic contract (estimated cost: $597, 000). Facility space is being prepared at JPL for delivery and installation of a simulator for calibration, functional testing, and developmental testing of the precision planet tracker portion of the A/G. The simulator will be mounted on a 4- x 8-ft slab of granite which will be

*Jointly Funded Under NASA Work Unit 125-17-02-01-55.

isolated from seismic vibration by an active control system. The temperature will be stabilized to eliminate thermal gradient variations greater than 0.1°F in the granite in order to control a 5-m optical path to less than 4 arc seconds of thermal drift.

TECHNICAL DISCUSSION; APPROACH GUIDANCE SUBSYSTEM

Recent studies reveal that measurement of optical axis alignments among the Canopus sensor, sun sensors, and planet tracker is desirable. The measurement of absolute pointing angle relationships will enhance the data processing to a greater degree than originally anticipated. Earlier concepts had indicated that a moderate undeterminancy of fixed angular alignments offsets would not degrade answers significantly, so long as accurate measurements of changes to pointing angles were obtained. Pointing angle inputs from auxiliary sun sensors and the Canopus sensor are subject to errors due to electrical measurement drifts, primarily. Ideally, all three bodies would be tracked by null-seeking optomechanical means. In optomechanical tracking, the major source of A/G nonrepeatable error is expected to be the presence of small particles in the precision gear trains. Orientation of the planet tracker field of view to the desired pointing angle has required the use of an entrance prism, as an alternative to the use of a more complex bracket, to point a major structural axis of the planet tracker toward the planet; this approach permits changes in field-of-view requirements (due to selection of a new trajectory, for instance) to be implemented by redesign of a single optical element, rather than by a revision to the spacecraft mounting interface.

SUMMARY

Basic program progress and status are satisfactory. The major interfaces still to be resolved are the location of auxiliary sun sensors and the A/G thermal control method. Schedules do not deviate from project guidelines to a significant extent.

PUBLICATIONS DURING REPORT PERIOD

<u>JPL SPS Contribution</u>

1. Chamberlain, F. R., and Barone, L. J., "Approach Guidance Flight Feasibility Demonstration," SPS 37-42, Vol. IV, pp. 48-49, December 31, 1966.

ANTICIPATED PUBLICATIONS

1. JPL SPS Contribution.

PROPULSIVE LANDER CONTROL SYSTEM

NASA Work Unit 186-68-02-24-55
JPL 384-66401-2-3440
R. J. Mankovitz

OBJECTIVES

The long-range objective is to define the final configuration for the propulsive lander control system. This includes definitions of: (1) system functional description (mechanization block diagram, flight sequence, weight and power estimates), (2) hardware performance requirements (drift, noise, null offsets), and (3) new component developments that are necessary. In addition, it is intended to perform computer and real simulations, using actual hardware, to verify system performance.

For FY 1967 the objective is to generate either an analog or digital computer control system simulation program and to investigate the feasibility of using radar, optical sensor, and programmer-controlled landing systems. The simulation will be detailed to include effects of hardware limitations (radar noise, thrust offsets, control system errors), atmospheric effects, and complete systems dynamics.

The results of this study can be directly applicable to Voyager capsule lander systems.

PROGRESS

Several simulation programs have been constructed (both 3- and 6-deg of freedom) which model various phases of the lander problem. Since the propulsive lander control system task effort will be discontinued at the end of the fiscal year, a decision was made to consolidate and document a single program. In addition, Langley Research Center has requested documentation on the simulation program for use on the Voyager project.

The simulation chosen was a 3-deg-of-freedom planar motion study, since it yields all pertinent translational and pitch rotational motion while only requiring moderate computer running time.

Excellent agreement in the translational and rotational motions has been obtained between the complete 6-deg-of-freedom program and the planar motion study because of the small out-of-plane motion and roll torques.

The simulation program has been completed and encompasses the modeling of the following phases: free-molecule flow regime, aeroshell deceleration, parachute deceleration, and actively controlled propulsive deceleration.

Some of the features included in the program are listed in Table 1.

Detailed documentation is being assembled describing the equations used, the input-output control available, and a mechanization block diagram of the system.

The analysis and configuration of the basic control system has been documented in JPL TR 32-1104 and JPL SPS 37-43, Vol. IV.

During this report period several areas were investigated, and are summarized in Table 2.

An alternate thrust control law was investigated to improve the capsule terminal conditions. This new mechanization is a constant thrust-to-weight ratio thrust law, as compared to the previously investigated computed acceleration thrust law.

The new mechanization decreased horizontal velocity at touchdown from 10.2 to 0.9 ft/s. Touchdown attitude was improved from 13.8 deg off vertical to 1.1 deg.

The use of parachute deceleration coupled with the propulsive descent was also investigated.

The parachute mode decreased fuel consumption from 450 to 225 lb, and decreased the engine maximum thrust levels and throttling ratios by 50%.

FUTURE WORK

The major effort at JPL concerned with soft landing systems for Voyager has been terminated. Since this was the main reason and the chief application for this advanced development program, it was directed that this project be discontinued. The results of this study are being transmitted to other NASA organizations that are picking up the effort.

PUBLICATIONS DURING REPORT PERIOD

JPL Technical Reports

1. Mankovitz, R. J., The Analysis and Configuration of a Control System for a Mars Propulsive Lander, TR 32-1104, March 15, 1967.

JPL SPS Contributions

1. Mankovitz, R. J., "Propulsive Lander Control System," SPS 34-43, Vol. IV, p. 84.

ANTICIPATED PUBLICATIONS

Meetings and Symposia Papers

1. Mankovitz, R. J., "The Analysis and Configuration of a Control System for a Mars Propulsive Lander," 2nd IFAC Symposium on Automatic Control in Space, Vienna, Austria, September 8, 1967.

Table 1. Features of Mars lander simulation program (3-deg-of-freedom planar motion)

Item	Features
Planet model	Round planet Surface features (terrain) Output variables calculated with respect to local horizontal
Atmosphere model	Major parameters calculated: Temperature Density Acoustic velocity Gravity Continuous surface wind Wind gradient Wind shear Surface tailoff Gusts
Aerodynamics	Major parameters calculated: Axial force coefficient Normal force coefficient Pitch damping coefficient Center of pressure Dynamic pressure Drag Lift Aerodynamic torque Plume effect Aeroshell staging
Doppler system	Terrain bias errors Complete beam acquisition logic Doppler and rate of change of doppler equations from capsule nose AGC included on transverse velocity loop

Table 1 (contd)

Item	Features
Propulsion	ISP varied with throttle ratio
	Mass depletion
	Fuel slosh forces and torques
	Throttle actuator dynamics and hysteresis
	Engine offset errors
Control system	Gyro dynamics
	Compensation networks
	Dynamic limiters
	On-board digital integration is modeled
System logic and switching	Flight computer logic and switching commands simulated
Input-output and general	Adaptive integration routine
	Automatic calculation of initial conditions
	Extremely easy data input
	Up to 50 outputs printed
	Up to 40 automatically scaled and labeled plots
	Complete flight log of salient events printed
	Three coordinate systems - inertial, body, and planet referenced

Table 2. Tasks for propulsive lander control system

System	Task
Control-doppler sensor	Evaluate surface terrain effects
Control-aerodynamics	Evaluate: a) effects of updated wind model (shear, gradient, gusts) b) use of parachute modes and aeroshell staging
Entire propulsive lander control	Investigate alternate thrust control law

REMOTE OPERATION OF A ROVING VEHICLE
NASA Work Unit 186-68-02-25-55
JPL 384-66701-2-3430
V. F. Anthony

OBJECTIVE

The objectives of this task are (1) to design, develop, and test components and systems with the capability of controlling the motion of unmanned planetary and lunar roving vehicles, (2) to investigate concepts and techniques pertaining to the earth-based and vehicle-based portions of Roving Vehicle Motion Control (RVMC) Systems, and (3) to continue work in the relatively unknown field of RVMC to produce designs, specifications, criteria, and recommendations directly applicable to unmanned planetary explorational missions.

APPROACH

JPL in-house effort is supplemented with a phased Contract: (1) to establish requirements and constraints for RVMC personnel, components, and systems, (2) to develop prototype vehicle-control and operations-control systems, test plans, procedures, and hardware from the requirements, (3) to test and verify the system(s) on an earth-based remote-control Control Test Model (CTM) vehicle, and (4) to finalize designs, and training and operations procedures, which specify RVMC requirements in detail. This effort is to be coordinated with the JPL Deep Space Net and Flight Operations, prior NASA Work Unit 127-51-01-02-55, "DSN Manual Remote Control Operations" and "Man-Machine Functions in Control of an Unmanned Roving Vehicle," NASA Work Unit 127-51-01-02-55.

PROGRESS

The following two major, related, on-going program activities, form the basis for the present conduct of the program as well as a basis for future planning.

The Study and Development Contract

Work started March 1, 1967 on the Roving Vehicle Motion Control (RVMC) contract at General Motors' (AC Electronics Division) Defense Research Laboratories. Figure 1 illustrates the phase I study contract program plan and schedule being followed by GM, and the results expected.

The Lunar and Planetary Mission Planning and Design Studies

Lunar and planetary mission planning committees are examining the potential capabilities of unmanned roving vehicles as practical tools for extended surface geophysical and biological exploration on the moon and planets.

PERFORMANCE CAPABILITY OF ROVING VEHICLES

As a result of studies to date, it is apparent that if roving vehicles are to be used to obtain significant lunar and planetary geophysical and biological data, the vehicle must be able to range over long distances for extended periods of time.

Estimates vary from "at least ten miles" up to "as much as 150 or possibly 900 miles" with mission life-times of 6 to 12 mo. Essentially, this affirms that the vehicle must have a performance capability which does not impose "unreasonable" constraints on the mission.

Compromises will be necessary in the vehicle system, constraints being imposed by limited communication bandwidth, and by the fact that communication with the vehicle (access time per day) may be limited in the planetary case. These are results of both long communication distance and rotation of the planet. These constraints are not so critical for lunar missions.

The above requirements and conditions present major challenges to the control system and control strategy. The particular problems to which practical solutions must be found are summarized in the following tasks.

Navigation

Because the vehicle must move between points kilometers apart, it will be necessary to provide navigation devices to prevent the vehicle from becoming lost in traversing from some point to another distant point, especially if the vehicle is committed to on-board automatic programs during periods where communication with the earth is not possible (e. g., due to planet rotation).

Imaging

Some form of visual data will be required to determine vehicle destinations, to select vehicle paths, and to examine areas or specimens in detail. It will be necessary to find ways of compressing data or to filter out nonessential data, in order to minimize the picture acquisition-recovery cycle and thereby minimize the load on the communications system. The imaging system can be operated in either of two modes, one for navigation and the other for high-resolution inspection of surface features.

Automatic Operation and Sensors

It may be necessary during planetary missions to commit the vehicles to long periods of movement over the surface without benefit of updated control from earth (e. g., during the Martian night). This mode of operation greatly increases the requirements placed on the on-board control system and associated navigation and computer systems, as well as on the protective and decision-making sensors. For example:

(1) How does the vehicle distinguish between a negotiable and nonnegotiable down-slope before irretrievably committing itself, especially in soft or loose soil?

(2) How does the vehicle distinguish and avoid nonnegotiable steps and trenches?

(3) Once the vehicle has stopped at a nonnegotiable obstacle or is at an impasse, how are the decisions made as to the best way to turn, or the best next step?

JPL in-house RVMC effort is presently divided between the interdependent tasks of providing technical inputs and direction to the contractor, and participation in the Voyager and the Advanced Lunar Study activities related to roving vehicles. As a result, the contractor is being supplied with continuously updated information, particularly in the areas of task 2, Basic Constraints, and task 3, Mission Objectives (see Fig. 1). The study teams are kept aware of roving vehicle system capabilities as the program develops.

FUTURE PLANS

The RVMC program in-house level of effort is being increased in FY 1968 to advance the program on a time-scale consistent with an expressed need for roving vehicles in the mid-1970's and, within the compressed time scale, to provide control systems for vehicles having greater range and more sophisticated self-contained, on-board control capability than initially anticipated.

The phase I contract extends into FY 1968 (December 1967). Phase II of the contract (breadboard design and fabrication) is scheduled to go into effect in the second quarter of FY 1968.

PUBLICATIONS DURING REPORT PERIOD

Contractor Reports

1. Roving Vehicle Motion Control, First Quarterly Report TR 67-34 (March 1 to May 31, 1967), General Motors Corporation, AC Electronics - Defense Research Laboratories, Santa Barbara, California (JPL Contract 951829).

ANTICIPATED PUBLICATIONS

Contractor Reports

1. Roving Vehicle Motion Control, Second Quarterly Report (June 1, 1967 to August 31, 1967), General Motors Corporation, AC Electronics - Defense Research Laboratories, Santa Barbara, California (JPL Contract 951829).

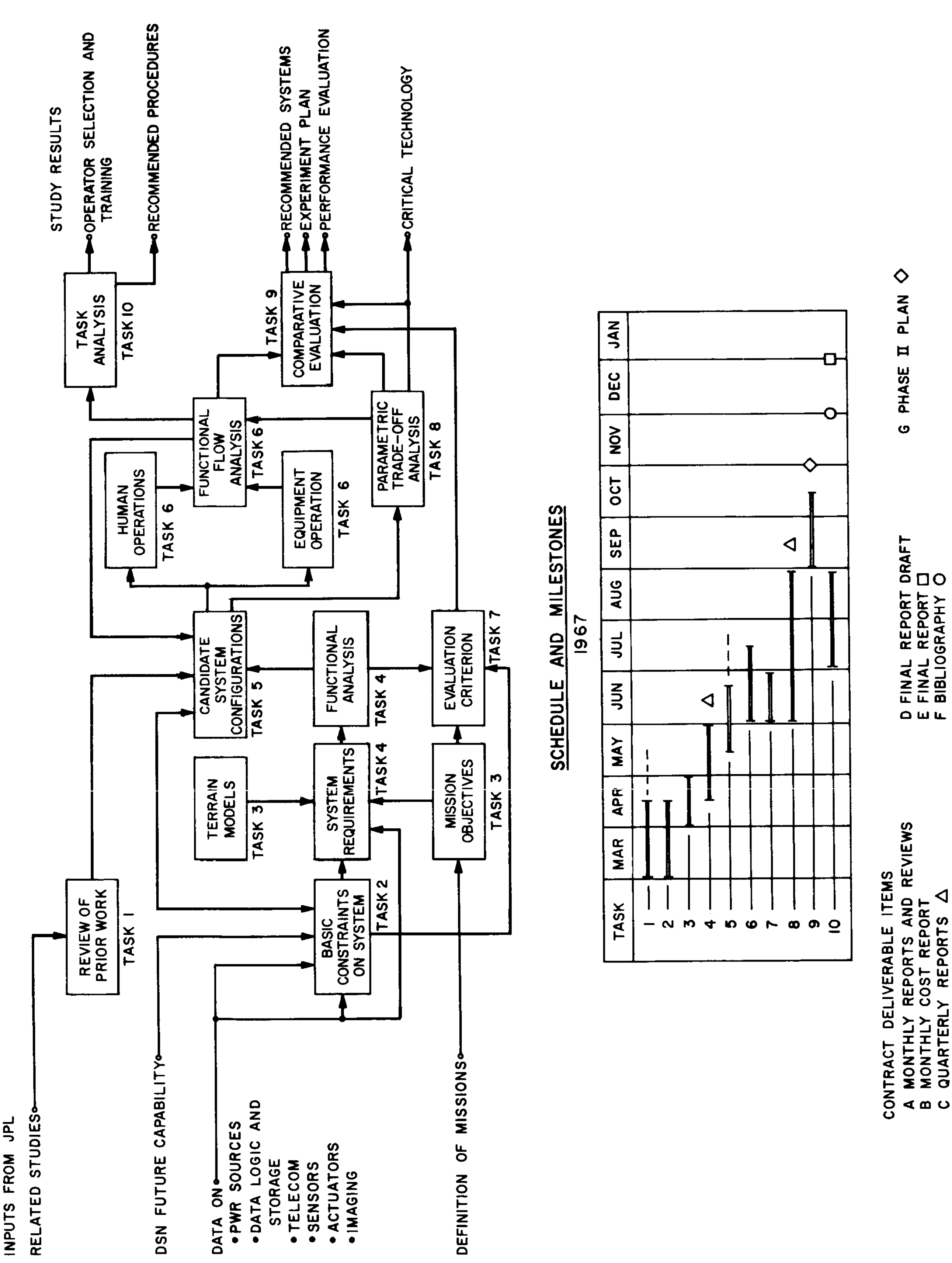


Fig. 1. General Motor's study contract plan and schedule

MILLIPOUND ATTITUDE CONTROL ACTUATOR DEVELOPMENT

NASA Work Unit 186-68-02-26-55
JPL 384-66801-2-3440

John D. Ferrera
Gerald S. Perkins

OBJECTIVE

The objective of this work unit for the second half of FY 1967 is divided into three subtasks:

(1) Continue to maintain an awareness and encourage and/or direct the feasibility demonstration and prototype evaluation of promising torquer concepts.

(2) Follow the testing of the hydrogen diffusion motors supplied by Advanced Technology Laboratories. For FY 1968 this subtask is being broken out into a new work unit: "MACAD-Hydrogen Diffusion Motor Test Contract," NASA Work Unit 186-68-02-34-55, JPL 384-69601-2-3440.

(3) Continue to study the Solid Propellant Electrical Thruster (SPET) concept developed by General Electric Company of Valley Forge, Pa. For FY 1968 this subtask is being broken out into a new work unit: "MACAD-Solid Propellant Electrical Thruster Contract," NASA Work Unit 186-68-02-36-55, JPL 384-69801-2-3440.

TORQUER CONCEPT EVALUATION

A wide spectrum of spacecraft torquing technology is required to assess the relative merits of various types of attitude control system actuators for planned and/or envisioned flight program applications such as planet flyby, orbiting, or landed operations. Areas of interest include thrusters capable of multilevel thrust operation, higher thruster total impulse/system weight for long-duration missions, actuators which will meet higher resolution requirements for cruise, orbital and terminal descent attitude control systems, and thrusters capable of micropound thrust operation. A more detailed description of the objective and approach of this subtask can be found in the FY 1967 and FY 1968 1122 backup sheets and the semiannual report for the first half of FY 1967 for this task number. In April a letter of interest was sent to 87 companies to determine those companies interested in, and capable of, doing work in the field of thruster development. The replies to this letter have been received and are being studied during the latter part of FY 1967 and the first half of FY 1968. These industries and the programs involved will be studied in detail through the letter information and personal and phone contact. This will be done to ensure that the most applicable hardware is available to meet future mission requirements. Time will also be spent in compiling information on anticipated future mission requirements as they become available. Where further development or comparison studies are needed in ensure this availability, a contract will be written in FY 1968.

HYDROGEN DIFFUSION MOTOR TEST PROGRAM

The hydrogen diffusion motors developed by Advanced Technology Laboratories are capable of steady-state thrust operation in the low-micropound range. The principle involved is based on the diffusion of hydrogen through a heated palladium-silver alloy. Its main advantage is in its simplicity of operation and no moving parts. The objective in this task unit for FY 1968 is to varify thrust and flow-rate data supplied by ATL. More information on the hydrogen diffusion motors is available in the last semiannual report and the 1122 backup sheets for this work unit. An RFP was circulated to perform the tests on these motors. Two replies were received since January 1, 1967 and evaluated. Lockheed Missiles and Space Company at Sunnyvale, California, has been determined to be best qualified to perform this testing. This contract (JPL Contract 951945) for $52,255 is currently in the process of being signed by Lockheed. The testing will last 10 mo from the starting date.

SOLID PROPELLANT ELECTRICAL THRUSTER (SPET) EVALUATION

Since the last report period work on (SPET), the Solid Propellant Electrical Thruster, under JPL Contract 951591 with General Electric, has proceeded in an orderly manner. A requirement of the contract was to deliver two SPET assemblies to JPL after testing at GE. The deliverable hardware is packaged in two parts: one is the trigger timing circuit (Fig. 1) and the other is the thruster assembly (Fig. 2) and firing circuit (Fig. 3).

The test configuration block diagram (Fig. 4) shows the relationship of the components required to fire a SPET thruster.

The work under this contract has been on schedule and has been performed in accordance with the work statement.

The firing circuit and fuel problems mentioned in the last semiannual report have been met by the following solutions.

(1) Firing Circuit. The firing circuit will make use of redundancy in the trigger tube. The capacitor will have bus leads in place of wire leads. These two changes will provide the reliability required for lifetimes typical of space flight missions.

(2) Fuel. Liquid Teflon of high wax-like viscosity is now being used in SPET. It has none of the problems encountered with the previous fuel. The I_{sp} remains the same.

It is planned to test the SPET thrusters at JPL under NASA Work Unit 186-68-02-22-55 in order to verify the results obtained at General Electric Company and to obtain life test data. The assemblies will then be used in a single-axis attitude control system simulation in-house test to be initiated within the next report period.

THRUST AND IMPULSE MEASURING TECHNIQUE

This subtask as detailed in the semiannual report for the first period of FY 1967 has been transferred to "Development of Actuator Processes and Measuring Techniques," NASA Work Unit 186-68-02-22-55, as of January 23, 1967 and is reported on for the second half of FY 1967 in the semiannual report for that task.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Perkins, G. S., "Solid Propellant Electrical Thruster," SPS 37-43, Vol. IV.

ANTICIPATED PUBLICATIONS

Contractor Reports

1. Final Report on Solid Propellant Electrical Thruster, General Electric Co., JPL Contract 951591 (NASA Work Unit 186-68-02-36-55).

2. Progress Reports on Hydrogen Diffusion Motor Testing, Lockheed Missile and Space Company, JPL Contract 951945 (NASA Work Unit 186-68-02-34-55).

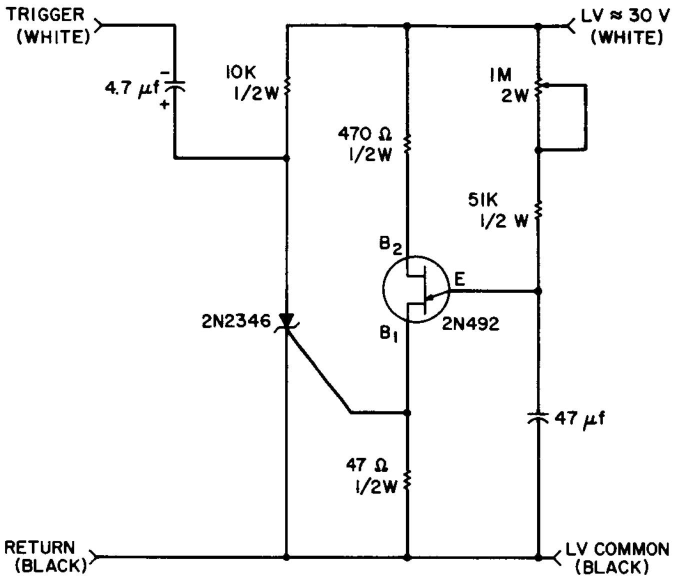


Fig. 1. Trigger timing circuit

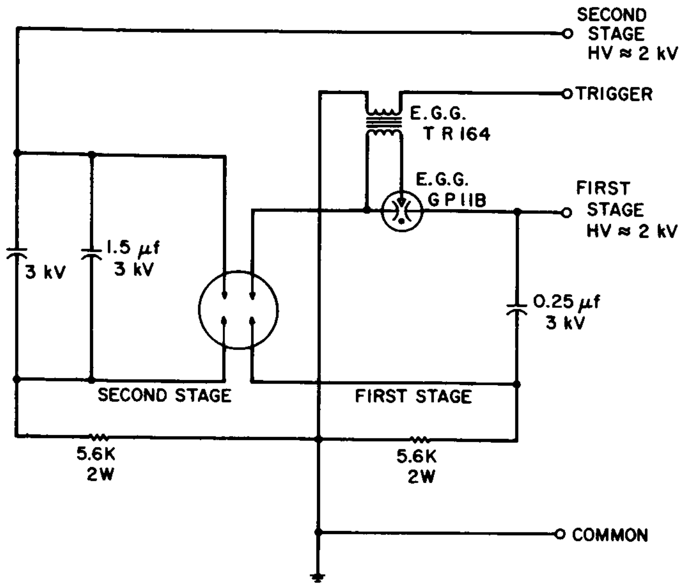


Fig. 3. Thruster firing circuit

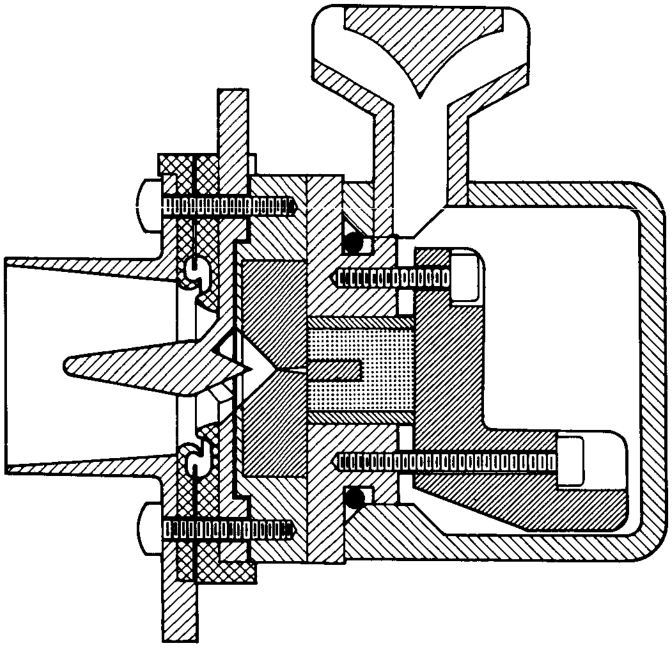


Fig. 2. SPET 108-C two-stage thruster assembly

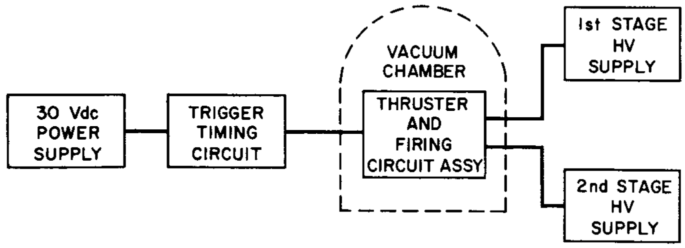


Fig. 4. SPET firing system

GSE ADVANCED DEVELOPMENT

NASA Work Unit 186-68-02-27-55
JPL 384-66901-2-3430

T. P. Cerney
F. Michael Horn
S. D. Moss

OBJECTIVE

The long-range objective is to develop the guidance and control ground support equipment technology to provide effective direction and leadership of contractors on future missions such as Mariner and Voyager. Within this objective, the first near-term goal is to develop a "GSE Unified Approach" concept. This concept is to be applied to the three guidance and control flight subsystems (electrical power, computers, and guidance and control) to provide an integrated approach to subsystem testing in the laboratory, manufacturing area, system test complex, and launch complex.

A second goal is to develop a precision light stimulus and a gas-valve-operation detector to provide quantitative end-to-end testing of the attitude control subsystem while installed on a capsule or spacecraft.

GSE UNIFIED APPROACH

This concept directs the use of the same basic GSE in all test areas where a flight subsystem exists as an assembled entity. Adaptors, buffers, or additional cabling are added in areas where more test points are available and where more detailed tests are required. The basic control element in all test areas is a small general purpose computer (purchased), which is replaced by a tape programmer in those areas where testing is repetitive and invariant.

Procurement of a commerical, general-purpose computer for the subject system is under way. A survey of computer hardware manufacturers was undertaken and has been completed. Machine and software specifications were formulated for inclusion in a statement of work. A synopsis follows.

Mechanical and Environmental Requirements

The system should be housed compactly in modular rack format, preferably with an integral operators console (24-in.-wide x 28-in.-deep modules). Special mounting structures should not be required.

Equipment should withstand normal room operating environments without special temperature or humidity control.

Arithmetic Requirements

(1) Arithmetic operations - fixed point, binary.
Hardware multiply and divide.

Indirect addressing.
Indexing.
Parallel arithmetic.

(2) Speed - 2-μs memory cycle time (max).
30-μs divide time (max).

(3) Memory - working memory: 8000-word magnetic core, expandable in 4000 increments (or 4096); 24-bit word length, excluding parity.
Bulk Memory - magnetic tape transport (45 in. /min; 556 bit/in.)

(4) Input/output.
Card reader - 100 card/min minimum.
Typewriter.
Multilevel priority interrupt capability with real-time monitor.
Direct digital output capability.
Direct digital input sensing.
Stall alarm; console sense switch interrupt control.

Software Capabilities

(1) Fortran IV or equivalent compiler which implements Boolean functions, preferably with bit manipulation capability.

(2) Symbolic assembler capable of in-line mixing with Fortran language. Monitor software permitting multiprogramming. Executive program chaining.

Table 1 lists those machines which most nearly meet the system requirements.

An automatic data processing equipment (ADPE) acquisition plan was submitted to NASA headquarters for approval on May 16, 1967. Approval is expected by July 1, 1967. A statement of work for the purchase requisition has been prepared, and proposal evaluation criteria have been developed. In the next period, the RFP will be initiated and a final vendor selected. The estimated equipment delivery date is December 1967.

System configuration studies will be undertaken to evaluate several alternative approaches, taking into account requirements developed during past flight programs, and desired goals for potential applications. The emphasis will be upon a system design with maximal flexibility and minimal buffering.

In the next period, work unit staffing will be raised to one and one-half engineers. Staff attendance at a vendor-operated training program is expected after the computer lease contract is let. Machine and assembly languages and hardware maintenance will be covered.

A software development flow plan will be prepared, with initial activity anticipated to be on a syntactical compiler and preliminary test routines. Fortran IV will be used throughout.

Table 1. Machines most nearly meeting system requirements

Company	Machine
Advanced Scientific Instruments	6020 6040
General Electric Company	PAC 4020 PAC 4040 PAC 4050-I PAC 4050-II
Honeywell Computer Control Division	DDP-124 DDP-224
Hughes	H3324
RCA	110
Scientific Control Corporation	655 660 670
Systems Engineering Laboratories, Inc.	840A

GAS VALVE OPERATION DETECTOR

The search for the improved techniques of sensing gas flow from the attitude control gas valves has resulted in the development of a transducer having favorable characteristics. This transducer is of the hot-wire anemometer type and consists of two 0.00015-in.-diam platinum (containing 10% rhodium) filaments mounted on a TO-5 integrated circuit header. The transducer was designed such that one filament, the active element, is positioned directly in the path of the nitrogen gas flow from the gas valve. The second filament, the passive element, is located on the header in such a manner that it is shielded from the gas flow. Since both the active and passive elements are physically located in close proximity, they are subjected to approximately the same ambient temperature variations. This temperature-tracking property provides the necessary temperature compensation for the flow sensor when connected in a bridge configuration. A differentially connected monolithic operational amplifier provides the required signal conditioning.

A prototype gas-valve-operation detector utilizing a hot-wire anemometer transducer has been designed and fabricated for evaluation testing purposes. This prototype, as shown in Fig. 1, is approximately 3 in. in length and 1 in. in diameter. An exploded view of the prototype detector is shown in Fig. 2, where the following items are depicted from left to right: (1) orifice disk, (2) transducer housing, (3) anemometer transducer, (4) electronics housing, (5) signal conditioning electronics, (6) connector plate, and (7) connector. Figure 3 shows the detector coupled to a typical Mariner spacecraft attitude control gas valve.

The prototype detector has undergone various phases of acceptance testing. The smallest and largest filaments used in these tests have been 0.0001- and 0.0005-in. diam, respectively. The 0.00015-in.-diam filament selection resulted from a compromise involving signal response times and mechanical rigidity. The prototype detector was satisfactorily tested over an environmental temperature range from 0 to +185°F. Some difficulty was experienced in testing the unit at vacuum pressures in the range of 10^{-5} to 10^{-7} torr. Due to the absence of atmospheric cooling, it was found that the platinum filament reached incandescence at a lower current as compared with ambient conditions. The vacuum bias current required for incandescence at 10^{-5} torr was determined to be approximately one-tenth that required for incandescence under ambient pressure conditions. One of two choices must be made for the anemometer to perform satisfactorily over a wide environmental pressure range. The first is to operate the anemometer at a bias current dictated by the highest specified vacuum. The second choice is to derive a bias current which is a function of pressure. The first choice appeared to be the simpler of the two. However, the loss of sensitivity, resulting from the anemometer operating at such a low bias current when subjected to atmospheric pressure conditions, makes this choice unattractive. Further study in this area utilizing an integrated circuit voltage comparator to replace the signal conditioning amplifier is planned. The second choice, a pressure-dependent bias current, was selected to solve the problem. The same characteristic which produced the problem, that of variation in thermal conductivity as a function of pressure, was utilized in an attempt to solve it. Different combinations of series sensistors and shunt thermistors were used in an effort to obtain a 10:1 variation in bias current over the full pressure range. The maximum variation obtainable utilizing this method was approximately 5:1. A solution to this problem has not been obtained to date. Temperatures from 75 to 215°F, at vacuum pressures of 10^{-7} torr, have little effect on the operation of the transducer.

Additional effort is presently being directed toward development of the piezoelectric ceramic transducer previously reported (see pp. 193-198 of JPL TM 33-322). The signal conditioning electronics are presently being designed to produce a nominal 10-Vdc output pulse which will correspond to the duration of the 20-mV random noise signal produced by the ceramic transducer. The signal conditioning electronics will consist of a linear, differentially connected, integrated circuit (IC) preamplifier followed by a linear IC connected as a modified integrator.

Some effort has been directed toward the fabrication of a very thin diaphragm and associated housing for the purpose of evaluating a series of foil-type strain gages.

Further evaluation of the hot-wire anemometer will continue in an effort to solve the vacuum problem discussed above. Evaluation of the ceramic transducer electronics will be accomplished and a prototype detector fabricated. Evaluation testing of the foil-type strain gages will be undertaken as well as a series of thin-film type thermistors which are presently being procured.

The development of a light stimulus for checkout of sun, star, or planet sensors will be initiated in the second quarter with an investigation of types of light sources and with laboratory measurements of incandescent lamps operated from regulated sources.

PUBLICATIONS DURING REPORTING PERIOD

None.

ANTICIPATED PUBLICATIONS

JPL SPS Contributions

1. Moss, S., "Gas Valve Flow Sensor," SPS 37-47 (in process).

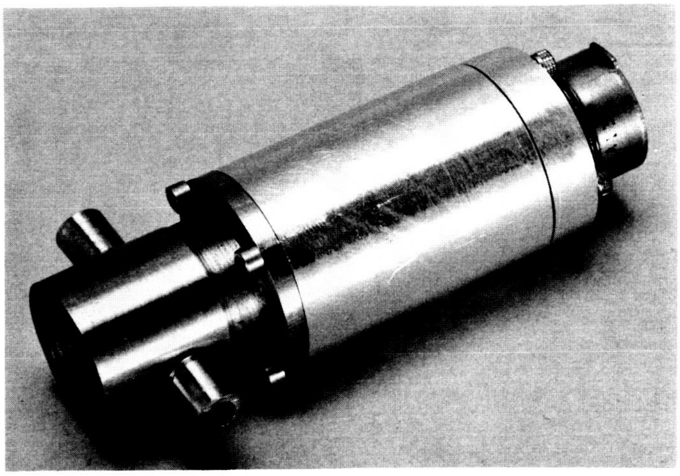


Fig. 1. Prototype gas valve operation detector

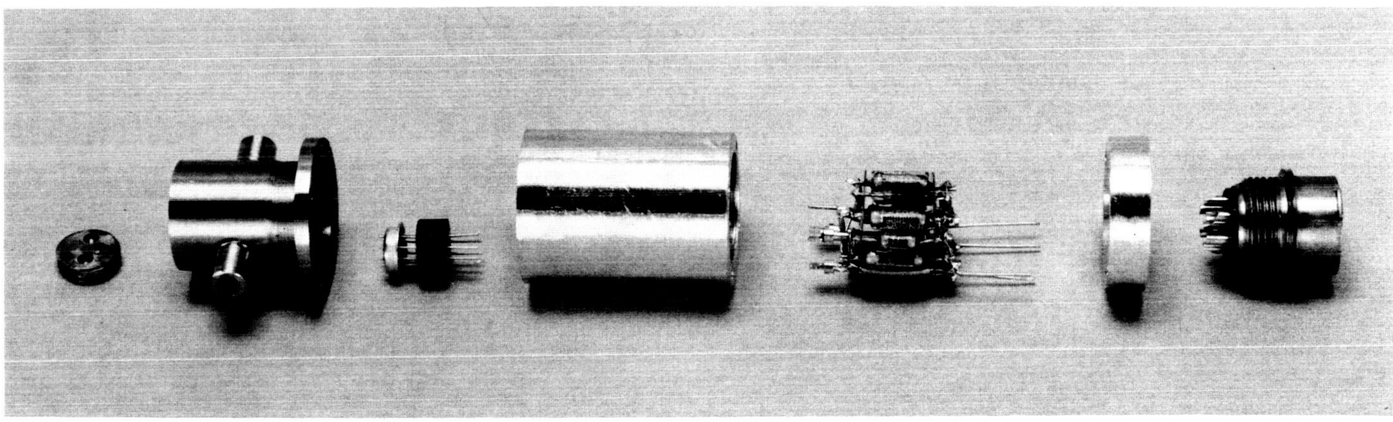


Fig. 2. Prototype gas valve operation detector -- exploded view

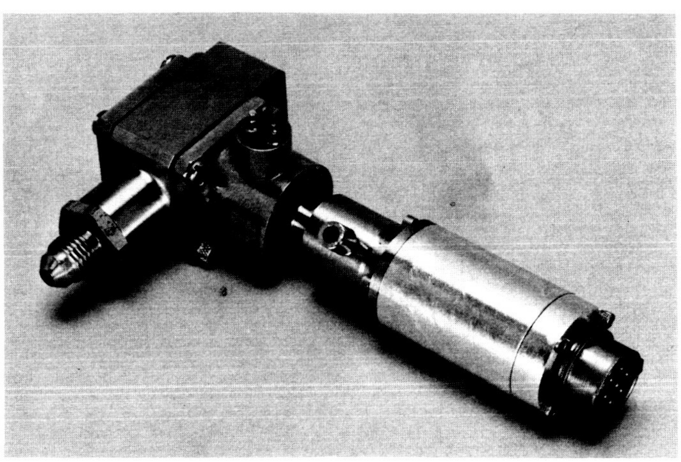


Fig. 3. Prototype gas valve operation detector connected to Mariner-type gas valve

OPTICAL SENSOR DEVELOPMENT

NASA Work Unit 186-68-02-28-55
JPL 384-68101-2-3440
J. M. McLauchlan

OBJECTIVE

The objective of this program is to study mechanization concepts and performance capabilities of an optical sensor for attitude and velocity sensing during the terminal phase of a capsule soft landing. This type of sensing is an alternate technical approach to the problem from the currently used Radar Doppler Velocity System (RADVS) on the Surveyor Program.

MECHANIZATION CONCEPT

The preliminary study was completed during this report period. The most significant results of this study are as follows. An optical sensor for spacecraft guidance and control during a soft landing must provide three-dimensional range and velocity information. Velocity would be reduced to zero from an upper limit of about 1200 ft/s (say, 375 m/s). A typical landing approach to Mars would be made in daylight with the sensor enabled at about 33,000 ft (say, 10 km) slant range to provide an altitude mark followed by retro-engine ignition at about 20,000 ft (6 km). Range and range rate accuracy of about ± 5% would be required from retro-engine lightoff to touchdown. Offsets should not exceed 5 ft and 5 ft/s, respectively.

A number of possible mechanizations was considered. First of all the source, its operating mode, and spectral wavelength offer a number of tradeoffs between power, detector efficiency, source efficiency, solar background noise, beam width, and other factors. Secondly, given an optical transmitter and detection system, there is a choice between a number of electronic mechanizations both continuous and pulsed. A continuous wave system was chosen on the basis that pulsed systems providing both range and range rate tend to be complex. The beam is modulated, and the modulation is stripped off after reflection from the ground. The signal then is processed in much the same way as in conventional radio frequency systems. The problems are different in detail when the modulation is carried on a carrier at optical rather than radio frequencies, but the general principles are the same. Phase difference between echo and transmitter determines the range in both cases, while the doppler shift in the modulation, not the optical doppler, determines velocity.

The details of this mechanization concept together with the principal problem areas are elaborated on in the cited reference. It is concluded that, using current technology, such a system is feasible and could be competitive with radar techniques.

EQUIPMENT PROCUREMENT

To initiate establishment of a laboratory capability of breadboarding and testing components of active optical systems, a procurement was initiated during this report period for a 15-mW helium neon gas laser.

FUTURE ACTIVITY

JPL's responsibilities on the Voyager Program have recently been redirected from spacecraft and capsule development to landed systems operation. To more directly support these objectives from a long-range standpoint, the principal future activities under this task are being oriented towards studies of mechanization concepts for active optical sensors for obstacle avoidance by landed roving vehicles and antenna pointing sensor. Additional equipment will be obtained to further establish Laboratory breadboard capability in active optical sensor technology.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contribution

1. Wright, H. R., "An Optical Sensor Concept for Guidance and Control of a Soft Landing Spacecraft," SPS 37-43, Vol. IV, pp. 100-107.

ANTICIPATED PUBLICATIONS

None.

ADVANCED SPACECRAFT DIGITAL MAGNETIC TAPE RECORDER DEVELOPMENT

NASA Work Unit 186-68-03-01-55
JPL 384-60901-2-3340

E. Bahm
W. Clement
J. Hoffman

OBJECTIVE

The objective of this work unit is to develop a standardized family of digital magnetic tape recorders that are lighter, less power-consuming, and more reliable than those presently available, with storage capacities of 10^6 to 10^{10} bits for use in future NASA spacecraft. The effort emphasizes the reliable long-life operation that will be required by the Voyager class of planetary mission.

ETM TAPE TRANSPORT DEVELOPMENT SUBTASK - J. K. Hoffman

The purpose of this subtask is to develop a basic reel-to-reel transport design embodying the significant improvements stemming from various studies conducted by JPL over the past few years. The ETM is a simple version of the hoped-for standard design. It provides a storage capacity in excess of 10^7 bits distributed over six tracks on 500 ft of 1/4-in. tape. One transport (ETM 2) will be extensively tested to thoroughly qualify the design, after which it will serve as a test bed for evaluating bearings, lubricants, tape, heads, and tape guidance schemes. Another unit (ETM 1) is being used in the servo speed control study covered elsewhere in this report.

General Background

Of foremost importance in the design of this equipment is that it reflects a 90% probability of operating continuously for at least a 6-mo period. As a result, the design is somewhat extreme in the size of belt pulleys and the lengths of belts. The drive system embodies the Kinelogic isoelastic principle on which considerable JPL past development effort has been expended. The main appeal of this principle is its mechanization simplicity.

Status

Various tests have been performed at JPL to verify transport performance, including start-stop time, flutter, skew, and its power and signal requirements. Fixed tape guides and rotating guides have been employed for comparison of power and flutter effects. Two different drive motor designs have been partially evaluated. Figure 1 is a photograph of the test setup currently being used for this work.

Tape transport housings with seals suitable for type approval environmental testing have been ordered. Preparation of an environmental test procedure has been initiated.

ETM 1 is currently being used by the servo study contractor in conduct of the "Servo-Controlled Tape Recorder Study."

Future Activities Planned

Performed tests and evaluation of the results will continue. An environmental test plan will be prepared. Upon completion of transport housings, the transport will be installed and checked out in preparation for TA testing. Fabrication of test fixtures will be initiated. TA testing will commence.

Future progress of this effort will be reported in conjunction with that of "Advanced Spacecraft Tape Transport Development."

ADVANCED SPACECRAFT TAPE TRANSPORT DEVELOPMENT SUBTASK - J. Hoffman

The purpose of this subtask is to implement and evaluate a considerably more complex version of the ETM design, and at the same time provide a combination of data rates and capacity consistent with future spacecraft requirements.

General Background

It is felt possible to increase the digital data capacity of the ETM tape transport to well in excess of 10^8 bits. The intent is to make selected design modifications facilitating an increase in the amount of magnetic tape that can be handled, while maintaining resonable optimization of weight, configuration, and power characteristics. The philosophy behind this design effort, therefore, is to modify the ETM design only to the extent necessary to fulfill the data capacity requirements as foreseen for the Mariner-class missions, and to provide tape speeds appropriate to the record and playback data rates required.

Status

A contract (formerly known as "10^8 Bit Tape Transport Development") was given to the Kinelogic Corporation some time ago. However, due to delays in the ETM development program, it was considered appropriate to hold up work until the ETM design concept could be better evaluated. A "hold" still exists on this project, pending completion of a preliminary design study to evaluate the tradeoffs between various parameters for optimizing the tape-transport design. This study has now been completed, and the results are being evaluated. Those design modifications that are indicated will be considered, and work will start on transport development during the next reporting period.

Future Activities Planned

(1) Complete evaluation of study results.

(2) Modify and/or supplement the Statement of Work as appropriate.

(3) Commence work on the Kinelogic subcontract for the tape transport development.

DIGITAL RECORDING TECHNIQUES STUDY SUBTASK - W. Clement

General Background

A determination of the optimum data storage system to be implemented for a specific application involves a detailed examination of a multitude of factors, including: (1) recording format, (2) logic complexity, (3) bit packing density, (4) signal detection and data reconstruction techniques, (5) bandwidth utilization, (6) recording and playback resolution, and (7) overall error rate. The purpose of this project is to develop a background of general information which can be brought to bear on specific data storage problems.

Status

A contract for $42,000 was placed with the Ampex Corp in late December 1966 and work started immediately. A mathematical model of the recording and playback process suitable for computer manipulation (Fortran II) has been developed. The degree of similarity between an experimentally obtained playback pluse and that yielded by the computer model is quite encouraging (see Fig. 2). Many computer runs have been made with different values of record-current, gap length, head-to-tape spacing, and tape permeability in order to determine how these values affect pulse length (hence packing density). The general conclusion is that the effect of the demagnetizing field in spreading the recorded flux transition is so great that the other factors are of negligible consequence.

Future Activities Planned

The remainder of the Ampex effort will be devoted to gathering and reducing computed data in order to show the relationship between bit density and error rate. The tape recorder characteristics fed into the computer will be those of the ETM so that experimental data will be available for comparison with some of the synthetic data.

It is anticipated that additional funded effort will be made using the results obtained from this study as a base on which to build.

SERVO-CONTROLLED TAPE RECORDER SUBTASK - E. Bahm and R. Piereson

(Note: This work was begun as part of this work unit in FY 1966. The work is continuing under the sponsorship of the Voyager Project, JPL 544-3GL20-1-3340.)

Objective

Develop a digital tape recorder control technique with the following features:

(1) Data at playback can be synchronized to an external high-rate clock.

(2) Variable rate input data can be recorded at a constant density.

(3) Tape can be driven smoothly over a wide speed range.

Progress

A contract for the development of a servo-controlled tape recorder was awarded to Borg Warner Corporation in October 1966. The contractor performed design studies for several approaches. The most promising design was released and the circuits were built. A low-resolution tachometer was installed in the ETM tape transport supplied by JPL. Initial performance tests were very successful. It was concluded that servo control of the motor should be feasible over a much larger speed range by the use of a high-resolution tachometer and a large motor.

Future Activities

The servo-controlled tape recorder will be completed and evaluated. It is planned to develop circuits for coding and decoding of variable rate data in a frequency doubling code. This effort is expected to be completed during the third quarter of 1967.

A follow-on study will be initiated. The objective will be to improve the reliability and operating life of present-day tape transports by developing a single-motor tape drive capable of moving tape at very slow speed as well as at high speed. If applied to single-speed tape transports, this tape drive will avoid speed-reducing devices in many cases and all high-speed rotating assemblies which, today, limit the operating life of most tape recorders. This tape drive can also be applied to multispeed transports having widely different tape speeds. In this case, speed reducers and high-speed assemblies cannot be avoided; but compared with the presently used two-motor tape drives, it will result in a considerable simplification and improved reliability.

MAGNETIC TAPE STUDY PROGRAM SUBTASK - W. Clement

This is a continuing program of evaluation and study of the electrical and mechanical characteristics of magnetic tape. The purposes are (1) to solve specific problems and (2) to keep abreast of new developments in the industry.

General Background

Magnetic tape is the most critical element in a tape data storage system. Little can be done with regard to optimization of characteristics for a particular application because tape production technology is extremely complex and costly, and spacecraft applications of tape constitute a negligible profit motive for the manufacturer. It, therefore, becomes important for JPL to conduct a tape-evaluation program in considerable depth so that characteristics of other elements (heads, transports, etc.), over which control can be exercised, may be optimally matched to the tape. It is also, of course, important to be able to consider the tradeoffs in performance characteristics between the different types and brands of tape; this capability also results from such an evaluation program.

Three specific problems are of concern with regard to spacecraft applications: (1) layer-to-layer adhesion of the spooled-up tape pack during long dormant periods, which could result in catastrophic failure of the tape transport, (2) tape wear, which could result in appreciable system degradation before completion of the missions, and (3) loss of tape-pack physical integrity under certain temperature conditions.

Status

A procurement package for a comprehensive test and evaluation program on magnetic tape has been prepared and RFPs are being issued.

Some in-house tests have been conducted in an effort to define the problem of the tape pack falling apart when the temperature is reduced. Information is needed to show how much temperature drop can be tolerated and whether the absolute temperature is a significant variable. No conclusions have been reached as yet.

Several different tapes have been evaluated in the ETM transport for bit packing density, signal amplitude, and modulation noise.

Future Activities Planned

During the next reporting period proposals for a tape study will be received and evaluated.

DRIVE BELT MATERIAL STUDY SUBTASK - J. K. Hoffman

Objective

Seamless Mylar belts have been the mainstay for torque transmission in spacecraft tape recorders for the past several years. Mylar films, however, are susceptible to permanent damage at temperatures in the vicinity of 70°C. Also, the fatigue life of Mylar belts is a serious problem in the design of long-life tape recorders. Confidence limits are low due to inconsistencies in base material and poor control of manufacturing processes. Kapton film belts are reported to withstand temperatures of 400°C without damage, and are also reported to possess superior fatigue life properties at conventional spacecraft temperatures.

The objective of this study is (1) to evaluate Kapton as a tape-transport drive-belt material and (2) to establish design and reliability criteria for both Mylar and Kapton, based on those properties found susceptible to control measures.

General Background

This program was originally designed to evaluate Kapton (a polyimide) as a drive-belt material, and was previously referred to as the "Kapton Drive Belt Study." Subsequent inputs relative to the state of the art of plastic drive-belt fabrication, and the chemical and physical characteristics of Mylar and Kapton led to a redefinition of the program technical requirements.

The intent is to investigate the properties of both raw materials, the belt manufacturing processes, and the effects of operational environment on installed belts. The results are to be applied to the recommendation of a set of specifications and procedures for the selection and handling of raw materials and for the manufacture, inspection, and application of seamless plastic drive belts.

Activities During Reporting Period

A procurement was initiated during the reporting period for a comprehensive study program.

Future Activities Planned

It is anticipated that bids will be solicited from appropriate sources during the next period.

BRUSHLESS DC MOTOR SUBTASK - E. Bahm and R. Piereson

(Note: This work was begun as part of this work unit in FY 1966. Sponsorship next year will be under "Servocontrolled Tape Recorder Study.")

Objective

The objective is to develop a miniature, reliable, high-performance, brushless DC motor design suitable for use in future spacecraft tape recorders. The short-term objective consists of design and fabrication of a motor which is 3/4 in. diam x 1 1/4-in. long (not including motor shaft extension) and which produces at least 40 g-cm torque with 25 V applied.

The long-term objective is to further develop this motor into a flight prototype capable of meeting all requirements of the Mariner environmental specifications.

Progress

A contract to develop a prototype motor was awarded to Roters Associates on February 9, 1966. By the end of June a basic motor design had been defined, and an electronic commutator circuit for a reversible motor had been developed. Some difficulty was encountered in obtaining an alnico IX rotor magnet with the required grain orientation. The contractor finally custom-ground a sample rotor from a piece of alnico IX bar stock. Measurements demonstrated that the material retained most of its magnetic properties.

The motor and electronic circuits have been built, and the motor seems to operate properly. Performance testing has started.

A speed-control circuit has been designed and built. It was tested with a simulated load.

Future Activities

Extensive performance testing will be conducted with and without the speed-control circuit. Immediately afterwards the environmental testing will follow and a report will be published.

A second unit of this motor is being procured for the study of advanced commutating systems. Design studies indicated that special commutating sequences, feasible only with brushless motors, should permit significant improvements of the motor efficiency. It is also anticipated that the rather complicated electronic commutator can be simplified.

The development of a much larger and very powerful brushless dc-motor is planned for the near future. It will be developed for the advanced "Servocontrolled Tape Recorder" and will be sponsored by that program.

BEARING AND LUBRICATION STUDY SUBTASK - J. K. Hoffman

Ball-bearing failure is one of the more common causes of spacecraft tape recorder malfunction. Failure modes are complex, involving many relationships of design and application. The objective of this task is to develop a better understanding of the underlying causes of bearing failures, and to determine the best bearing/lubricant combinations for the various classes of tape recorder bearing applications. It is expected that better understanding of the nature of bearing failure will facilitate improved bearing specification and screening.

General Background

Because the reliability of magnetic tape transports used in spacecraft applications has proved to be significantly dependent upon that of the bearing elements, a continuing program to investigate and evaluate various bearings and bearing lubricants relative to their characteristics of torque, life, stability of operation, and environmental compatibility. Considerable paper research has been conducted for additional background in the subject. Several organizations specializing in bearing test and analysis have been visited, and their operations discussed. Several types of bearing test equipment have been observed and evaluated. Procurement of bearing test equipment has been initiated. A number of candidate lubricants have been tested. An outline of general requirements of the evaluation program has been prepared.

Activities During Report Period

High-temperature and corrosion tests of additional selected lubricant samples were conducted. Of the liquid lubricants tested so far, only three or four oils and five greases appear to warrant further investigation. Some preliminary investigation of the possibilities of dry lubricants has been made. Some bearing performance and life test tooling has been designed and is being fabricated. Bearing torque test equipment is still not available due to delay in the manufacturer's development program. Hopefully this procurement will be completed during the next reporting period.

Future Activities Planned

Evaluation of temperature capabilities of selected lubricants will continue. State-of-the-art developments in bearing and lubrication applications and evaluation techniques will be studied. Procurement of test equipment will be expedited as possible. Bearing life/performance vs operating speed and duty cycle tests will be conducted.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Clement, W. G., "A Magnetic Recording Tape Layer-to-Layer Adhesion Tester," SPS 37-42, Vol. IV.

2. Clement, W. G., "Linear Bit Packing Density on Standard Instrumentation Magnetic Recording Tapes," SPS 37-42, Vol. IV.

ANTICIPATED PUBLICATIONS

JPL SPS Contributions

Intermittently.

Contractor Reports

1. A Miniature Brushless D-C Motor for Spacecraft Applications.
2. Direct Recording of Variable Rate Digital Data on Magnetic Tape.

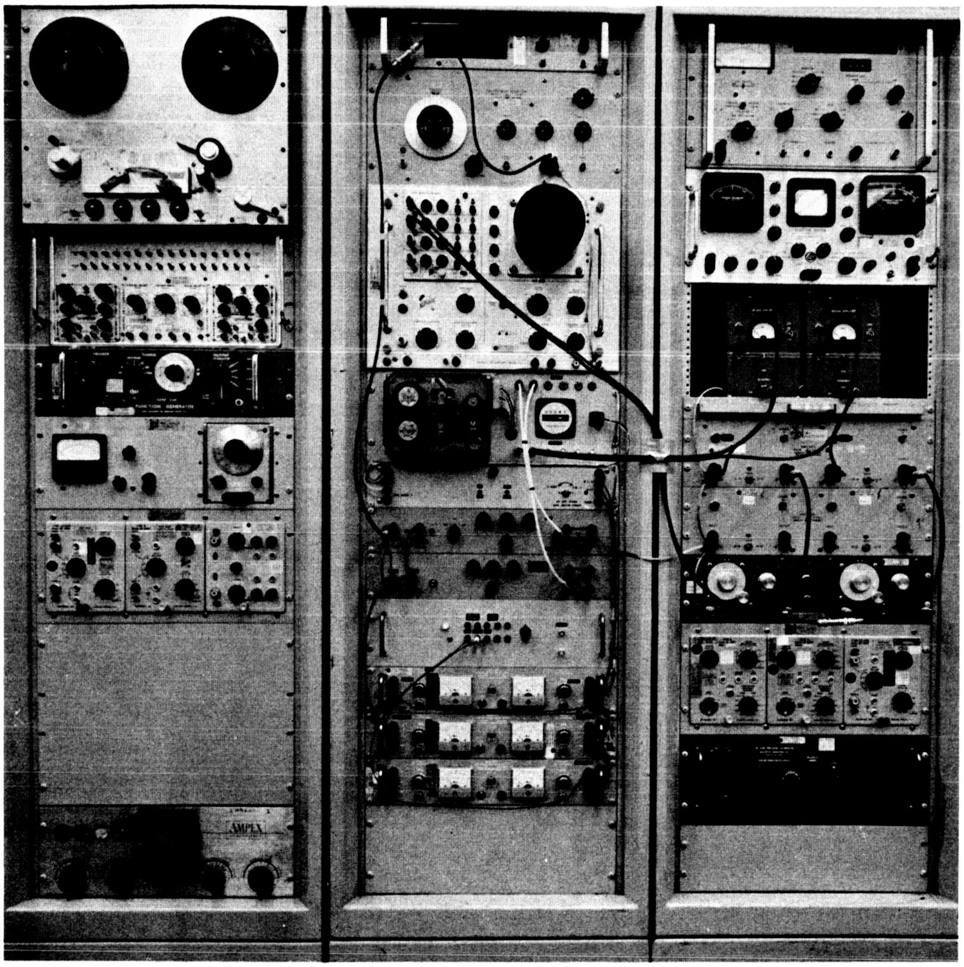


Fig. 1. Test setup

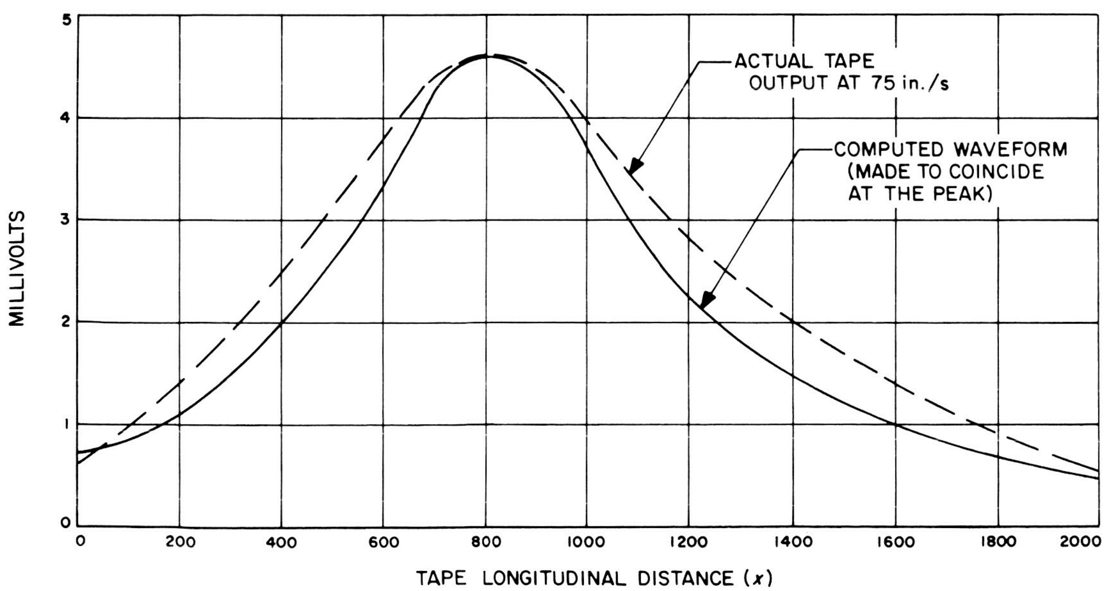


Fig. 2. Playback pulse

SCIENCE DATA HANDLING SYSTEM DESIGN

NASA Work Unit 186-68-03-03-55
JPL 384-60801-x-3240

M. Perlman

OBJECTIVE

The long-range objective is the formulation of advanced concepts and the development of analytical design techniques for synthesizing the spacecraft science data automation system.

PROGRESS

Logic Simulation

The logic simulation program (developed under contract by the Planning Research Corp.) is now operational. It is currently being used:

(1) To simulate the logical behavior of a digital integrator.

(2) To determine cycle lengths and successive states of shift registers with linear and nonlinear logic feedback functions.

Combinational Logic Minimization

The evaluation of computer programs for the minimization of simultaneous Boolean functions is continuing. A specific application is in the generation of a hyperbolic voltage curve as a function of time by means of digital techniques. The continuous voltage curve is

$$v(t) = \frac{1000}{at + b} \tag{1}$$

where a and b are constants. This serves as an acceleration voltage for a single focusing mass spectrometer (mass range 10 to 50). The subunits comprising the digital acceleration voltage generator are shown in Fig. 1. The feedback shift register has a recurrence relationship of:

$$a_n = a_{n-5} \oplus a_{n-9} \oplus a'_{n-1}\, a'_{n-2} \cdot \; \cdot \; \cdot \; a_{n-9} \tag{2}$$

The digitally generated voltage curve is shown in Fig. 2 and can be expressed as:

$$v(n) = \frac{1000}{\left[\frac{anT}{511}\right] + b} \tag{3}$$

where nT represents the sample time interval (see Fig. 2). The two-level AND-OR matrix in the canonical form requires approximately 8000 diodes. The 12 outputs are Boolean functions of the nine inputs. Results of the share library program

LLBAM-1197 (previously reported) were compared with those of the proprietary IBM-MIN 6 Program. The latter proved to be superior with respect to computation time and the magnitude of the size of problems the algorithm can handle. The LLBAM-1197 program yielded a solution when the problem was partitioned into four sets of three functions of the nine input (Boolean variables). Results were obtained with the IBM-MIN 6 with a partition of two sets of six functions of nine variables.

Other programs (e.g., House and Rado algorithm) required special input-output equipment not available at JPL.

An effort has been initiated to modify the existing IBM-MIN 6 program for handling larger problems in one pass. Concurrently a feasibility study is under way for the development of a local extraction algorithm for multioutput logic minimization on a IBM 360 generation machine.

Data Automation System for a Mariner 1971 Mass Spectrometer

A functional design of a Data Automation System was completed for a double-focusing mass spectrometer. The MS and its associated DAS in Fig. 3 is being proposed for a Mariner 1971 descent into the Martian atmosphere.

MS Characteristics

$$R = \frac{K_1}{B} \sqrt{\frac{m}{e} V}$$

where R = radius of curvature of ion collected by electrometer

B = flux density of permanent magnet

and

$$\Delta V_{89-90} = 2.25 \text{ V}$$

$$\Delta t_{89-90} = 25.4 \text{ ms}$$

Quantization of the output of the electrometer is based on 0.5% accuracy over the range of 1 to 10 V.

Word	Information	Bits	Total
1.	Identifier		15
2.	V(0)		
	*Mass No. 10 t, A, S_1S_2	9, 11, 2	22
	.		
	.		
	.		
	*Mass No. 90 t, A, S_1S_2	9, 11, 2	22
n.	V(t), t at 5 sec	11, 9	20
n + 1	Engineering Meas.		56

Buffer Requirements

Buffer requirements are based on the presence of a maximum of 33 mass numbers (i.e., 12-24, 36, 38, 40, 44, 45, 51, 53, 82, 84, and 86) are 828 bits.

Transmission Time

Maximum transmission time is based on an average transmission rate of 160 bit/s is 5.16 s.

Near Maximal-Length Cycles with Linear Feedback Shift Registers

The behavior of synchronously operated shift registers with linear and nonlinear logic feedback has been studied in detail. The FSR has application in counting, scaling, addressing, buffering, error detection and correcting, sequence generation, etc.

Cycle lengths of $2^s - 1$ can be realized with an s-stage linear FSR. These are termed maximal. The simplest of these, in terms of implementation, are those with two-tap feedback which satisfy the linear recurrence relationship:

$$b_n = b_{n-i} \oplus b_{n-s}$$

also (4)

$$a_n = 1 \oplus a_{n-i} \oplus a_{n-s}$$

*t = time; A = electrometer output; S_1S_2 = scale switch combination.

$$= a_{n-i} \oplus a'_{n-s} \tag{5}$$

where $1 \leq i < s$

Unfortunately, there are many values of s for which maximal length cycles cannot be realized with two feedback taps. In these cases, four or a higher even number of taps are required. As the number of pairs of feedback taps increase, the complexity of the feedback function grows sharply.

Two classes of near-maximal-length cycles have been discovered which are realizable with linear FSRs. With s-stages, cycle lengths of 2^s-2 and 2^s-4 are attainable with effectively three feedback taps. The linear recurrence relationships are (with few exceptions):

$$\begin{aligned} a_n &= 1 \oplus a_{n-i} \oplus a_{n-j} \oplus a_{n-s} \\ &= a_{n-i} \oplus a_{n-j} \oplus a'_{n-s} \end{aligned} \tag{6}$$

where $1 \leq i < j < s$.

Two-tap maximal-length linear FSRs require two or three active gates in the feedback. Near-maximal-length cycles can be realized with four or at most five active gates. These implementations are with NAND gates with provision for NAND-AND operation. The memory element is a 0 enable RS flip-flop where the next-state Q may be expressed as:

$$Q = S' + Rq$$

and

$$R'S' = 0$$

See Fig. 5 and Tables 1 and 2.

Near-maximal-length cycles have been shortened by the addition of a word detector as follows:

$$a_n = 1 \oplus a_{n-i} \oplus a_{n-j} \oplus a_{n-s} \oplus W \tag{7}$$

where

$$W = a_{n-1}^{\alpha_1} a_{n-2}^{\alpha_2} \cdot \cdot \cdot a_{n-s+1}^{\alpha_{s-1}} \tag{8}$$

and

$$a_{n-i}^{\alpha_i} = a_{n-i} \text{ for } \alpha_i = 0$$

$$a_{n-i}^{\alpha_i} = a'_{n-i} \text{ for } \alpha_i = 1$$

A W may be found which shortens a near-maximal cycle length of $2^r - 2$ to every odd length from 1 through $2^r - 1$ with the exception of $2^{r-1} - 1$.

A W may be found which shortens a near-maximal cycle length of $2^r - 4$ to every length 1 which is relatively prime to $2^r - 4$.

FY 1968 ACTIVITIES

Redundancy Reduction of Data Emanating from the Scientific Instruments

Work has already been initiated in statistical coding at the source (i.e., source encoding). Analytical studies are under way and will continue in the optimization of information transferrals by minimizing the average code word length. The choice of codes will be governed by channel capacity and the price of implementation.

Redundancy reduction will also be investigated from the viewpoint of predictors and interpolators.

Error-correction codes will be analyzed for the irredundant data samples.

ADPE Computer Selection

Approval has been received from NASA to purchase a general-purpose computer for simulation of advanced data system concepts. An intensive comparison is being made between some 12 computers which will serve to simulate future DAS tasks. A selection on the basis of competitive bids will be made.

Combinational Logic Minimization

The modification of the IBM-MIN 6 will be completed. The feasibility study for the development of a local extraction algorithm for multioutput logic minimization will be completed. The results of this study will lead to a decision as to whether or not a rewrite of the IBM-MIN 6 should be attempted for the IBM 360 generation machine.

A milestone chart for this work unit is shown in Fig. 6.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

Table 1. Linear feedback configurations for FSR cycle lengths of $2^s - 2$.

s	i	j	$2^s - 2$
4	1	2	14
5	1	3	30
6	1	2	62
7	1	5	126
8	1	2	254
9	2	6	510
10	2	3	1022
11	1	3	2046
12	2	7	4094
13	-	-	----
14	1	2	16328
15	3	5	32766
16	1	2	65534
17	1	11	131070
18	1	12	262142
19	1	7	524286
20	1	14	1048574

Table 2. Linear feedback configurations for FSR cycle lengths of $2^s - 4$.

s	i	j	$2^s - 4$
4	1	3	12
5	1	2	28
6	-	-	--
7	1	4	124
8	-	-	---
9	1	2	508
10	1	5	1020
11	1	4	2044
12	1	3	4092
13	1	2	8188
14	-	-	----
15	1	12	32764
16	1	7	65532
17	1	14	131068
18	5	9	262140
19	7	10	524284
20	5	7	1048572
21	1	6	2097148

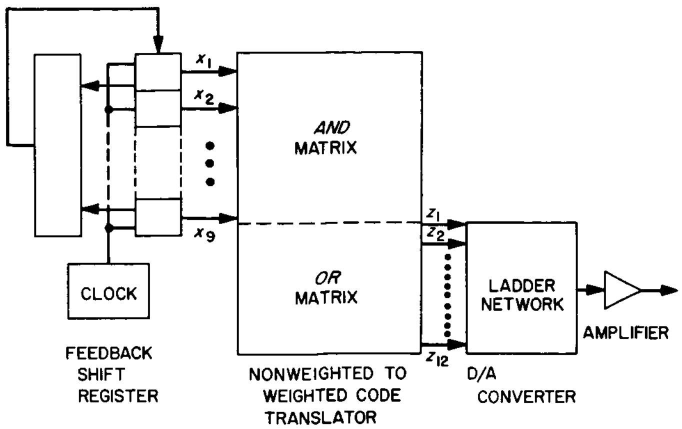


Fig. 1. Digital acceleration voltage generator

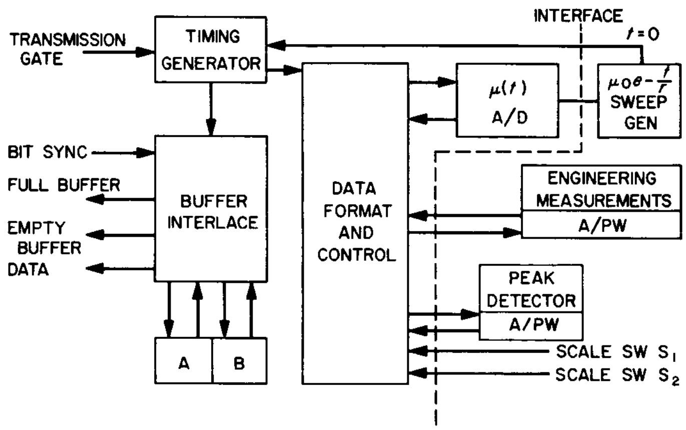


Fig. 3. DAS functional block diagram for a mass spectrometer

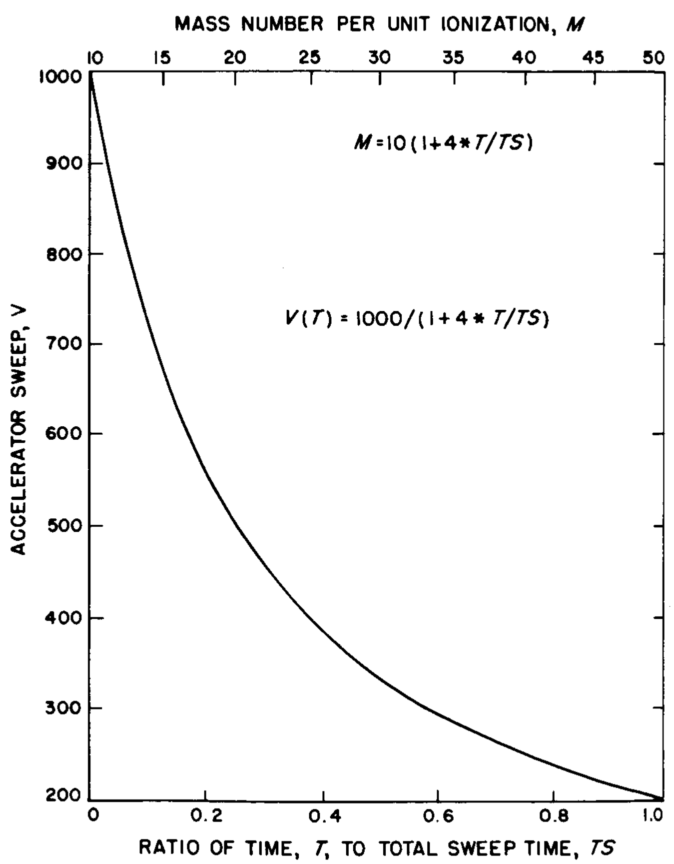


Fig. 2. Acceleration voltage vs time (normalized) - hyperbolic curve

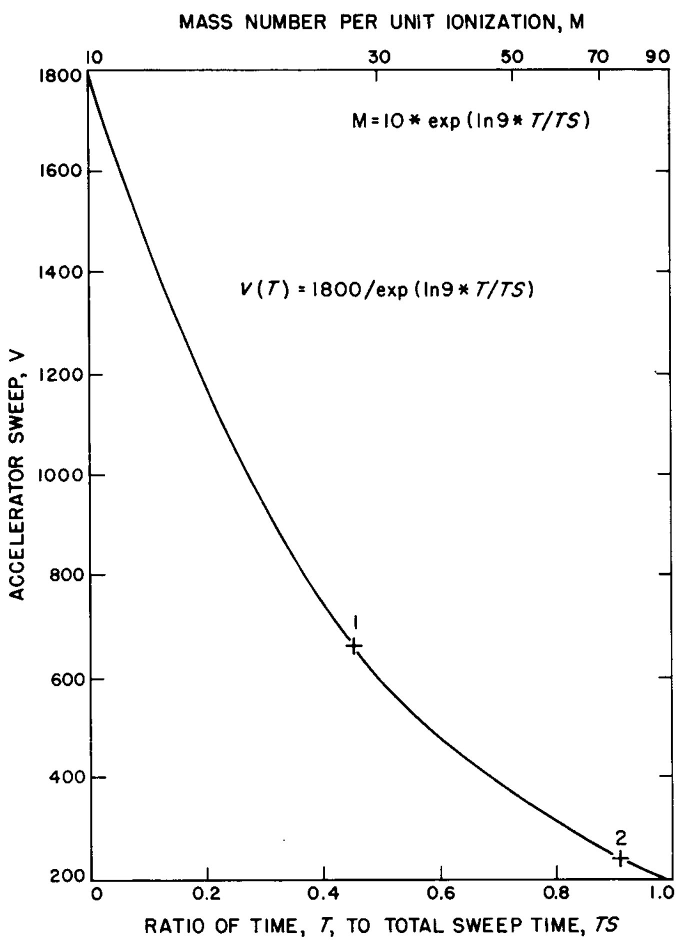


Fig. 4. Acceleration voltage vs time (normalized) — exponential curve

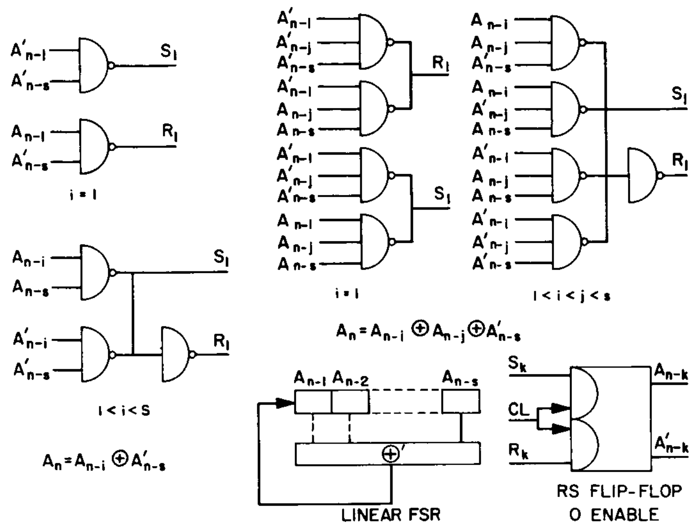
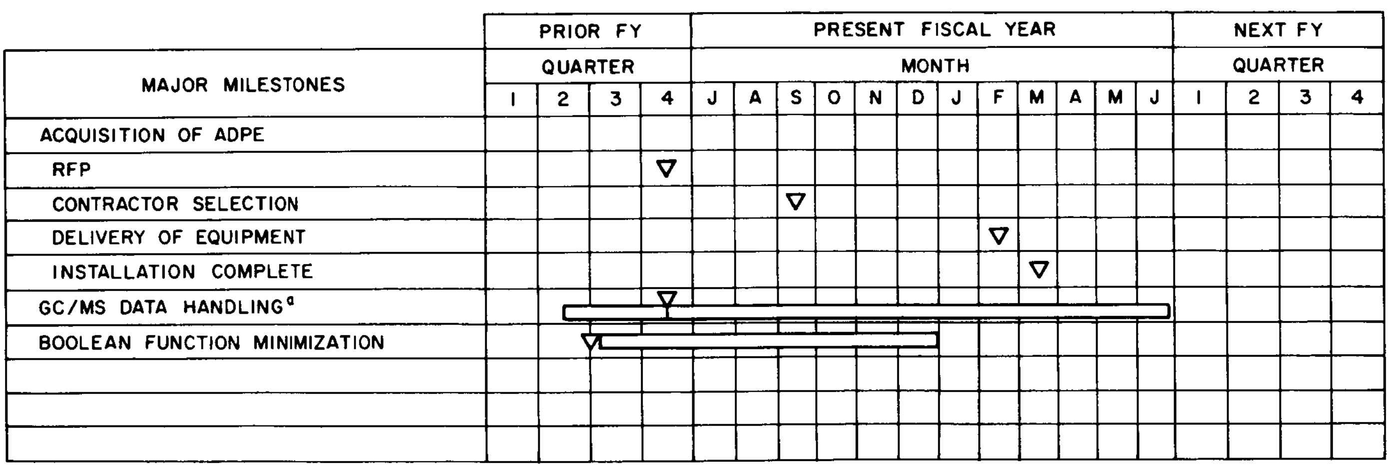


Fig. 5. Feedback implementation for maximal and near-maximal linear FSRs



[a] STUDIES ARE IN-HOUSE AND INCLUDE CODING, DATA COMPRESSION, AND PROCESSING.

Fig. 6. Milestone chart for science data handling system design

SCIENCE DATA HANDLING SYSTEM IMPLEMENTATION

NASA Work Unit 186-68-03-04-55
JPL 384-61601-2-3240

J. W. Spaniol

OBJECTIVE

The purpose of this task is the development of hardware and hardware techniques to implement Science Data Subsystems. Three areas of investigation have been explored: (1) scientific instrument simulation, (2) instrument interface consideration, and (3) data handling implementation. Laboratory equipment and techniques have been developed to construct and analyze breadboard models, in concert with "Science Data Handling Systems Design," NASA Work Unit 186-68-03-03-55. The technologies being developed under this task are generally applicable to the Mariner Mars 1971 capsule. Where possible, the requirements of the Mariner Mars 1971 mission are imposed in order that spilloff from these tasks can contribute to its design.

PROGRESS

A data library system is being built to record and reproduce instrument analog signals. A goal of this system is the recording of data from the Mariner Mars 1971 mass spectrometer in the second quarter of FY 1968. Investigation of the data handling techniques needed for the Mariner Mars 1971 mass spectrometer has shown the need for a digitally generated exponential sweep voltage under control of the Data Handling System. A piecewise linear approximation generator has been designed and a breadboard model is being built. The breadboard will use integrated circuitry throughout, including a digital-to-analog converter. A more sophisticated breadboarding system, adaptable to automatic wiring methods, has been designed using commercial integrated circuit carrier and socket assemblies. The Mass Spectrometer Sweep Generator breadboard will use this approach. Figures 1 and 2 show the completed breadboard.

An analog-to-digital converter (ADC) approach using a commercial large-scale integrated (LSI) circuit is being evaluated. The breadboard converter shown in Fig. 3 represents a large reduction in volume and components in comparison with present converters. The rapid advances of LSI technologies will allow even greater size reductions.

Two integrated circuit logic families in identical logic systems have been successfully temperature-tested and placed on life test. An LSI ten-stage counter shift register circuit, being developed under the Voyager task, appears to have many applications throughout the Science Data Subsystem. A careful study of these applications is being made to realize the full advantage of weight and power savings that this circuit represents.

Figure 4 presents a milestone chart for this task.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

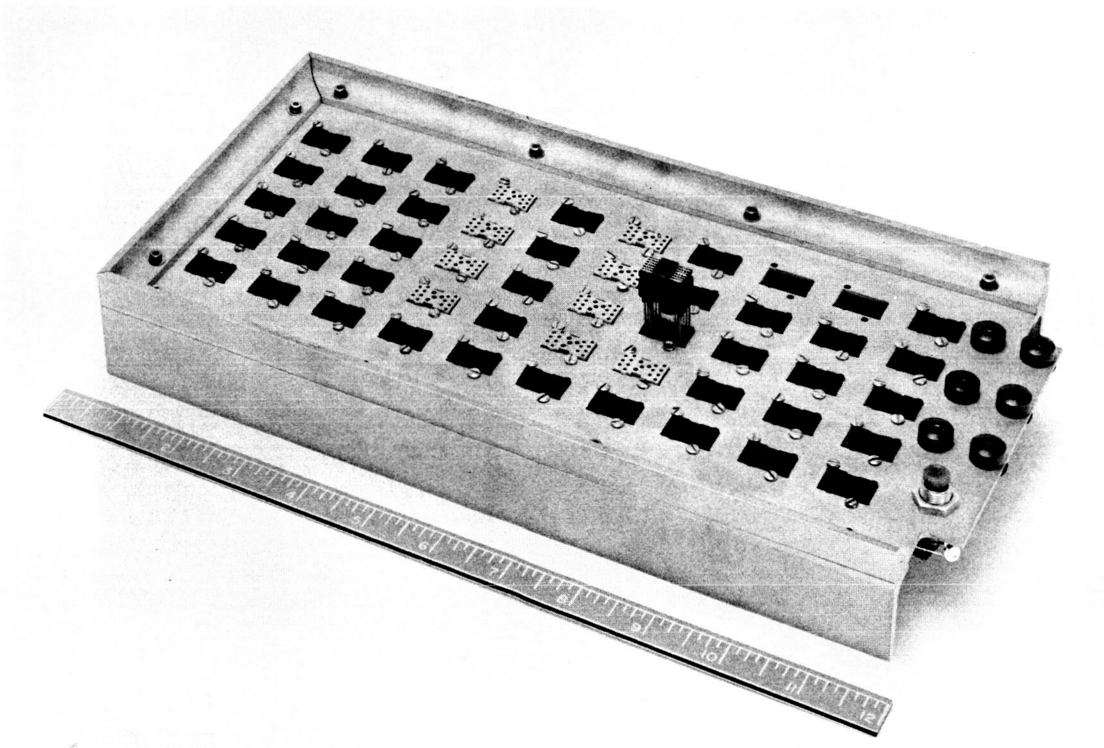


Fig. 1. Mass spectrometer sweep generator breadboard (top)

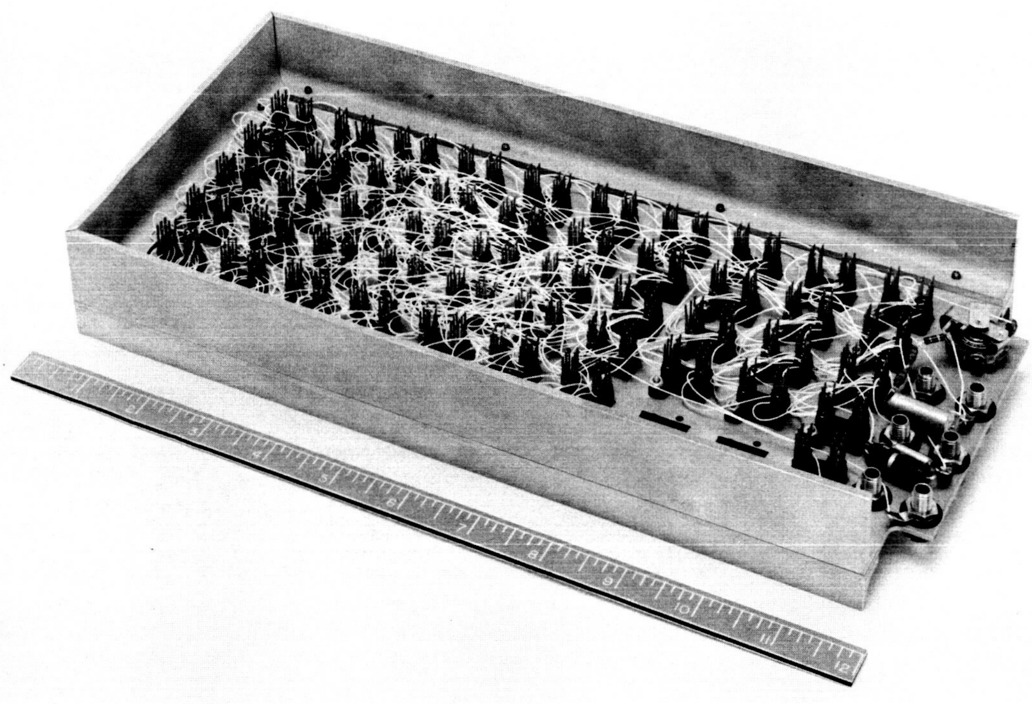


Fig. 2. Mass spectrometer sweep generator breadboard (bottom)

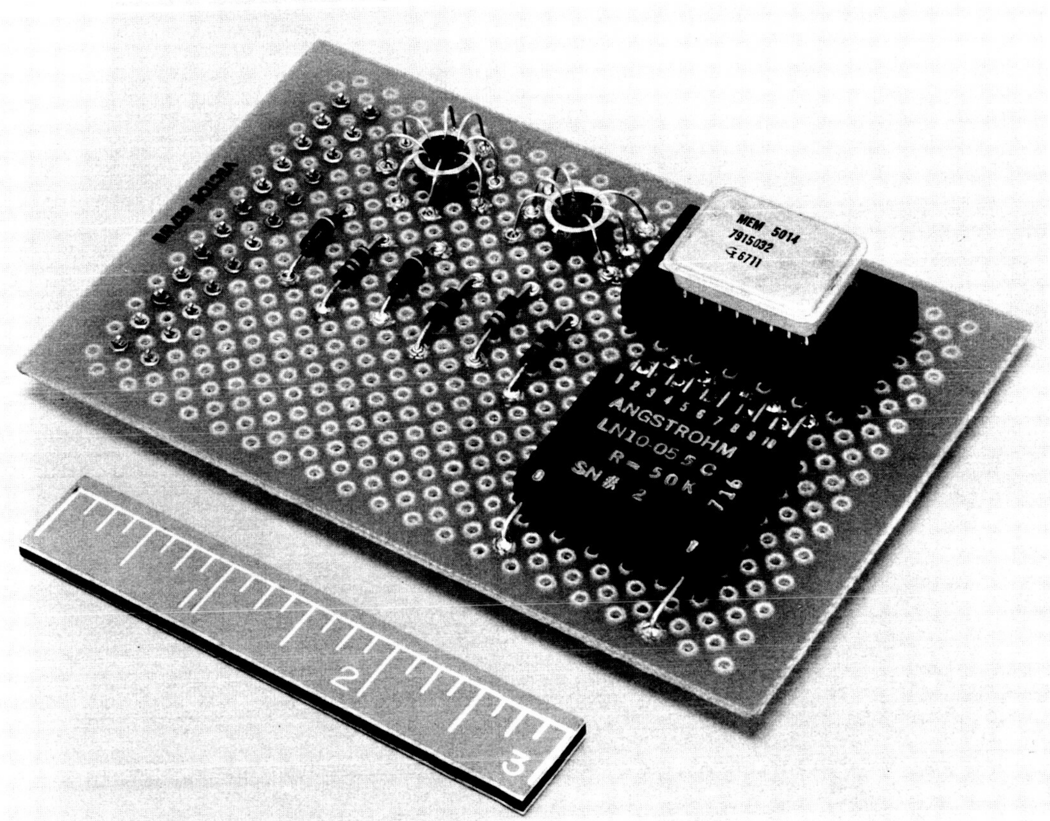


Fig. 3. Breadboard converter

MAJOR MILESTONES	PRIOR FY				PRESENT FISCAL YEAR												NEXT FY			
	QUARTER				MONTH												QUARTER			
	1	2	3	4	J	A	S	O	N	D	J	F	M	A	M	J	1	2	3	4
1 DATA LIBRARY SYSTEM PROCUREMENT			▽																	
2 DATA LIBRARY SYSTEM COMPLETE					▽															
3 IC LOGIC FAMILY COMPARISONS				▽																
4 DESIGN SPECIFICATION FOR IC A/D CONVERTER (NOTE)							▽													
5 EVALUATION OF LSI TO A/D CONVERTER				▽																
6 RECORD MS DATA ON DATA LIBRARY						▽														

NOTE:
TO BE WRITTEN ONLY IF EVALUATION INDICATES A NEED, AND THEN ONLY FOR THE LOGIC PORTION.

Fig. 4. Milestone chart for Space Science Handling System

VIDEO MODULATION TECHNIQUES

NASA Work Unit 186-68-03-06-55
JPL 384-67701-2-3340

G. L. Fultz

OBJECTIVE

This task is intended to study the interaction of the noisy communications media with both analog and digital video signals. The major area of investigation is concerned with how best to encode the video signal and its attendant synchronization information so that the communications channel will introduce minimal and acceptable forms of degradation in the received pictures.

APPROACH

An established processing facility, which includes a video test console for generating and reproducing video signals, an RF test console for simulation of AM, FM, and PM communication channels, and an SDS 930 digital computer, will be employed to evaluate various proposed analog and digital video systems. Efforts will be directed toward improving the quality of recovered pictures through analysis of the statistical manner in which the various types of channel noise affect the video signal and its synchronization.

IN-HOUSE TELEVISION DATA COMPRESSION STUDIES

Phase II of the Television Data Compression Study, which is concerned with the evaluation of the effects of a noisy transmission channel on compressed data, is complete.

Four typical noise-corrupted pictures in Fig. 1 show the effect of bit errors in the reconstructed pictures and the effectiveness of two addressing schemes. The important parameters associated with these pictures are listed in Table 1.

It is planned that the video test console will be used to aid in evaluation of the Mariner Mars 1969 high-rate (video) telemetry link.

Table 1. Important picture parameters

Picture number	Compression algorithm	Aperture	Addressing scheme	Net compression	Channel bit error rate
31	Zero-order predictor	4	(6.3)	2.55	0.95×10^{-3}
32	"	4	Normal	2.36	0.99×10^{-3}
39	"	4	(6.3)	2.55	0.51×10^{-2}
40	"	4	Normal	2.36	0.55×10^{-2}

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

Phase II Report.

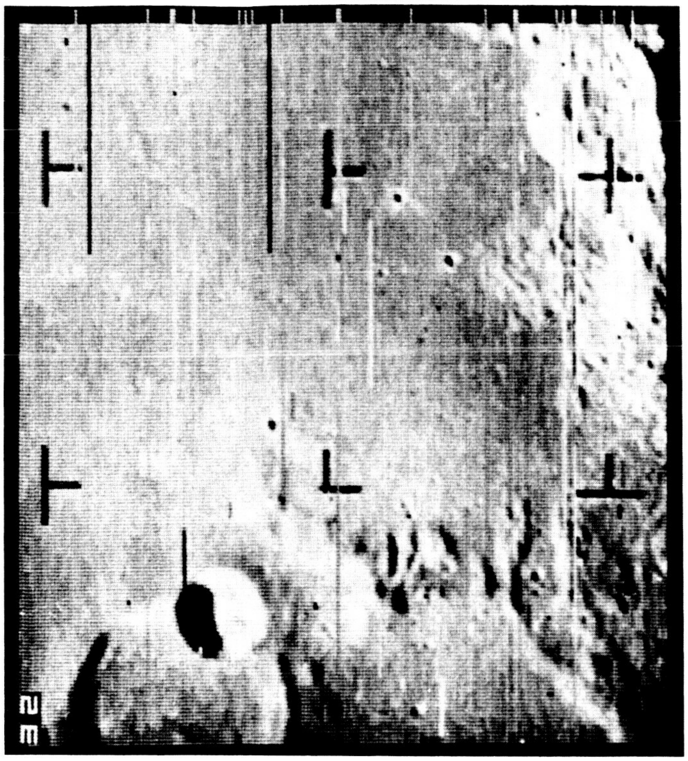


Fig. 1a. Typical noise-corrupted pictures

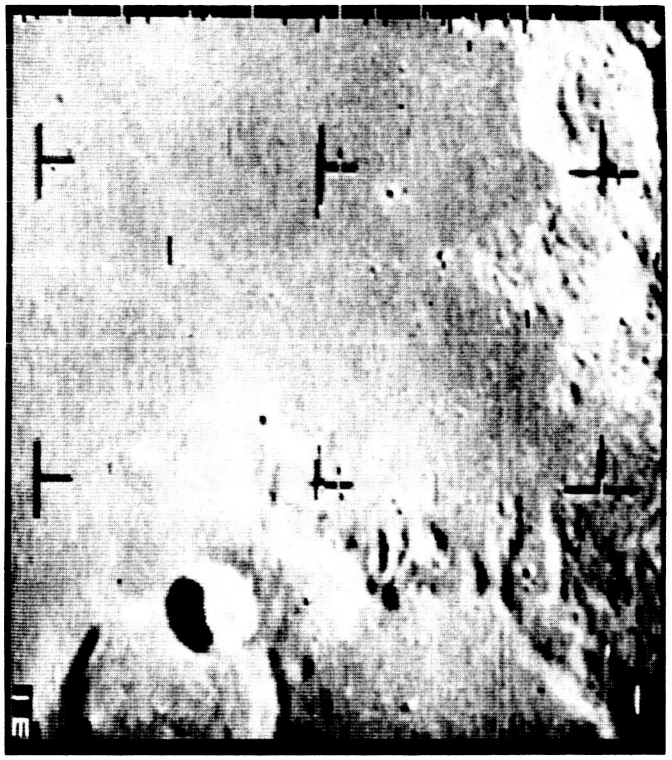


Fig. 1b. Typical noise-corrupted pictures

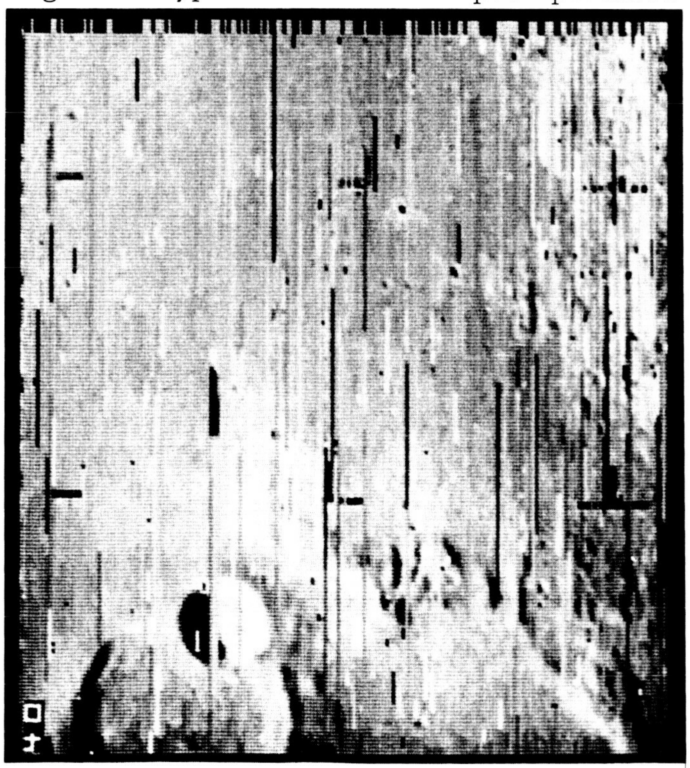


Fig. 1c. Typical noise-corrupted pictures

Fig. 1d. Typical noise-corrupted pictures

CAPSULE RELAY ANTENNA STUDY
NASA Work Unit 186-68-04-02-55
JPL 384-67301-2-3330
K. E. Woo

OBJECTIVE

The objectives of this task are to develop a 400- MHz antenna for use on planetary landing capsules and to study the interactions between the capsule relay antennas and the capsule configuration. The program for the current fiscal year included (1) a study of the basic mission objectives and (2) an antenna feasibility study. In FY 1968 antenna prototype fabrication and test evaluations will be conducted.

CSAD RELAY ANTENNA

In supporting the CSAD program, a circularly polarized capsule relay link antenna operating at 400 MHz is being designed. From size and weight consideration, the coaxial cavity type of radiator has been chosen for development. An experimental model of the antenna is under construction. For minimum weight, the cavity is made up of fiberglass honeycomb covered with aluminum face sheets (except at the radiating aperture). The overall dimension of the antenna is about 13 in. OD and 12 in. high, and the total weight is about 4.5 lb. The gain of the antenna is expected to be around 6 dB. This relay antenna will be completed and delivered during the second quarter of FY 1968.

PUBLICATIONS THIS REPORT PERIOD

None.

ANTICIPATED REPORTS

None.

RADIO FREQUENCY TEST CONSOLE

NASA Work Unit 186-68-04-03-55
JPL 384-61201-2-3341

F. J. Charles

OBJECTIVE

The RF test console was developed for use as a precision laboratory tool to aid in the evaluation of various modulation techniques and their interaction with the RF system. The console is currently being used to assist in the development of the Mariner Mars 1969 block-coded high-rate telemetry system. In addition the console will be used extensively in support of "Capsule Telemetry Relay Link" and "Capsule Telemetry Direct Link," spacecraft telemetry and video studies, and spacecraft and capsule command modulation systems development.

RADIO FREQUENCY TEST CONSOLE, PHASE I CONTRACT

The RF test console phase I contract (JPL Contract 950144) was awarded to Westinghouse Corporation, Baltimore, Maryland, on March 5, 1964. The primary goal of this contract was to build a precision 50-MHz signal-to-noise mixer and demonstrate experimentally that an RF signal-to-noise ratio could be set and maintained within a tolerance of ±0.3 dB over a 4-h period. In addition, Westinghouse was required to study practical methods of mechanizing an equivalent DSIF transmitter/receiver pair (including possible future capability) with an accuracy and precision of at least an order of magnitude better than that obtainable from an operational DSIF transmitter/receiver pair.

The significant results and the conclusions reached during the course of this contract are summarized in a final report. In addition, the detailed experimental and analytical work performed under this contract is available in the form of appendices to the final report. For convenience, some of the more important results are reported here.

The primary aim of the contract was to establish the accuracy with which average signal-to-noise ratios at 50 MHz could be set. Toward this end, a matrix of all possible signal-to-noise settings (25×10^4 of them) was arranged into four quadrants; ten settings from each quadrant, plus the corner setting, were selected at random. The mean, variance, and standard deviation of each quadrant were calculated. By comparison, each quadrant was a subset of the total matrix population, and a mean, variance, and standard deviation were calculated for all the readings. From these calculations, a 95% confidence interval with 5% tolerance limits was applied; it was determined that no more than 5% of the readings would fall outside of ±0.155 dB. In addition, as a result of extensive testing, the noise power spectral density at the signal-to-noise mixer output was determined within ±0.05 dB by the frequency response of the mixer. The effort under phase I was completed, including a design review and delivery of a final report, in March 1965.

RADIO FREQUENCY TEST CONSOLE, PHASE II CONTRACT

After careful consideration of the results of the phase I contract, it was decided to award a follow-on contract (i. e., phase II) to Westinghouse on June 29, 1965, for the purpose of building the RF test console. The objective of this contract was to implement the subsystem design plan, developed during the phase I contract, in accordance with a prescribed list of specifications. These specifications established as a design goal the accuracy and precision of the RF test console to be an order of magnitude better than that of an operational DSIF transmitter/receiver pair. In the previous report period the contractor had completed the fabrication and system testing of the RF test console and had conducted a formal design review (December 7, 1966) for JPL personnel. The RF test console was delivered to JPL in February 1967 and subjected for a 2-wk period to extensive testing prior to final acceptance by JPL. At this point in time the operator's manual and some of the support documentation (i. e., details of filter design, etc.) have been formally accepted by JPL. Currently a rough draft version of the final report is being studied by the JPL cognizant engineer.

A functional block diagram of the RF test console and a photograph of the actual test complex are shown in Figs. 1 and 2, respectively.

Cost of phase I	$122,478
Cost of phase II	$395,660
Total cost	$518,138

PUBLICATIONS DURING REPORT PERIOD

Contractor Reports

1. "Filter Design and Performance," Appendix B of Radio Frequency Test Console, Phase I, Final Report, Westinghouse Corporation, Baltimore, Maryland.
2. Operator's Manual, Appendix C of Final Report.
3. Maintenance Data, Appendix D of Final Report.

ANTICIPATED PUBLICATIONS

Contractor Reports

1. Final Report for Phase II Contract.

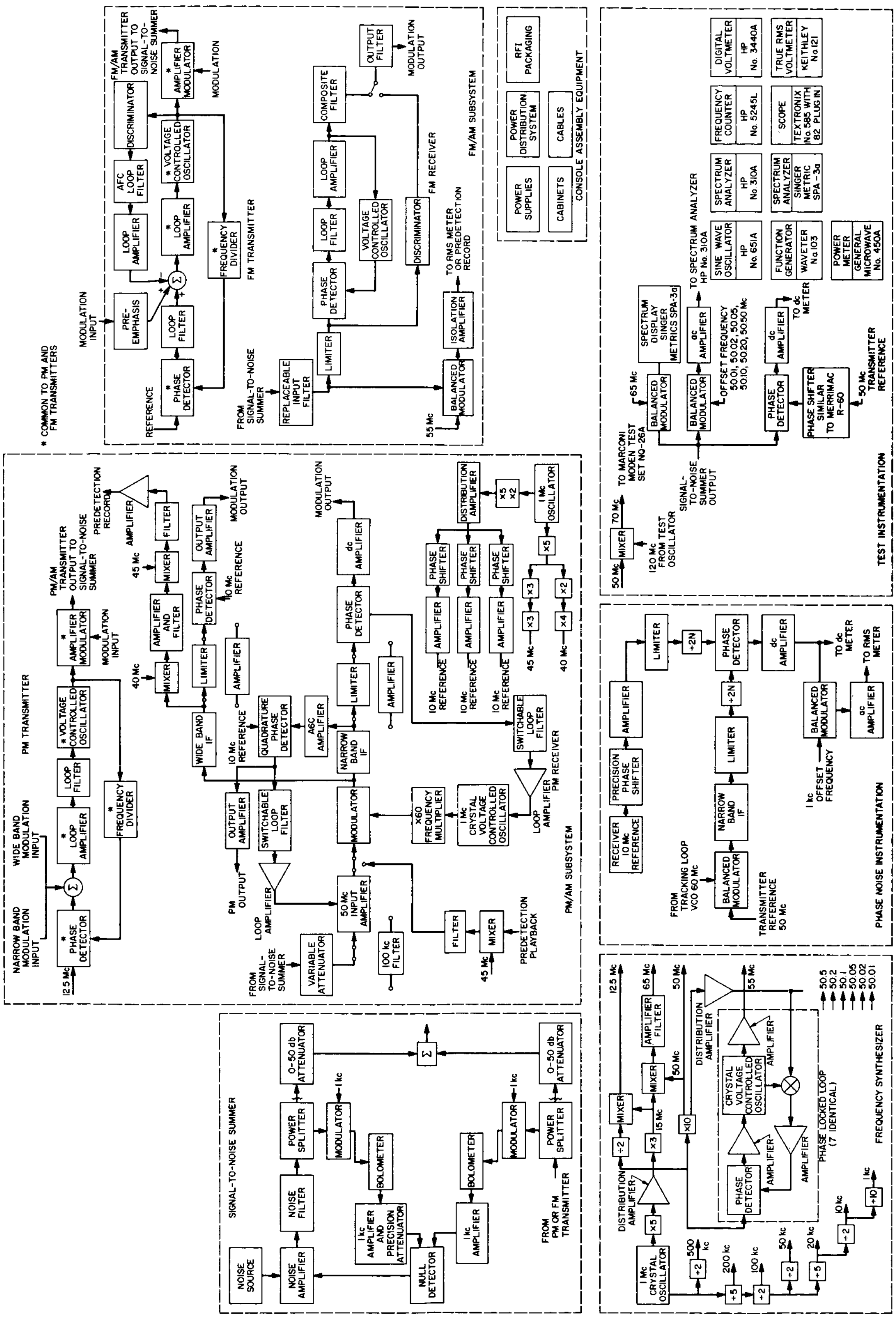


Fig. 1. Functional block diagram for RF test console

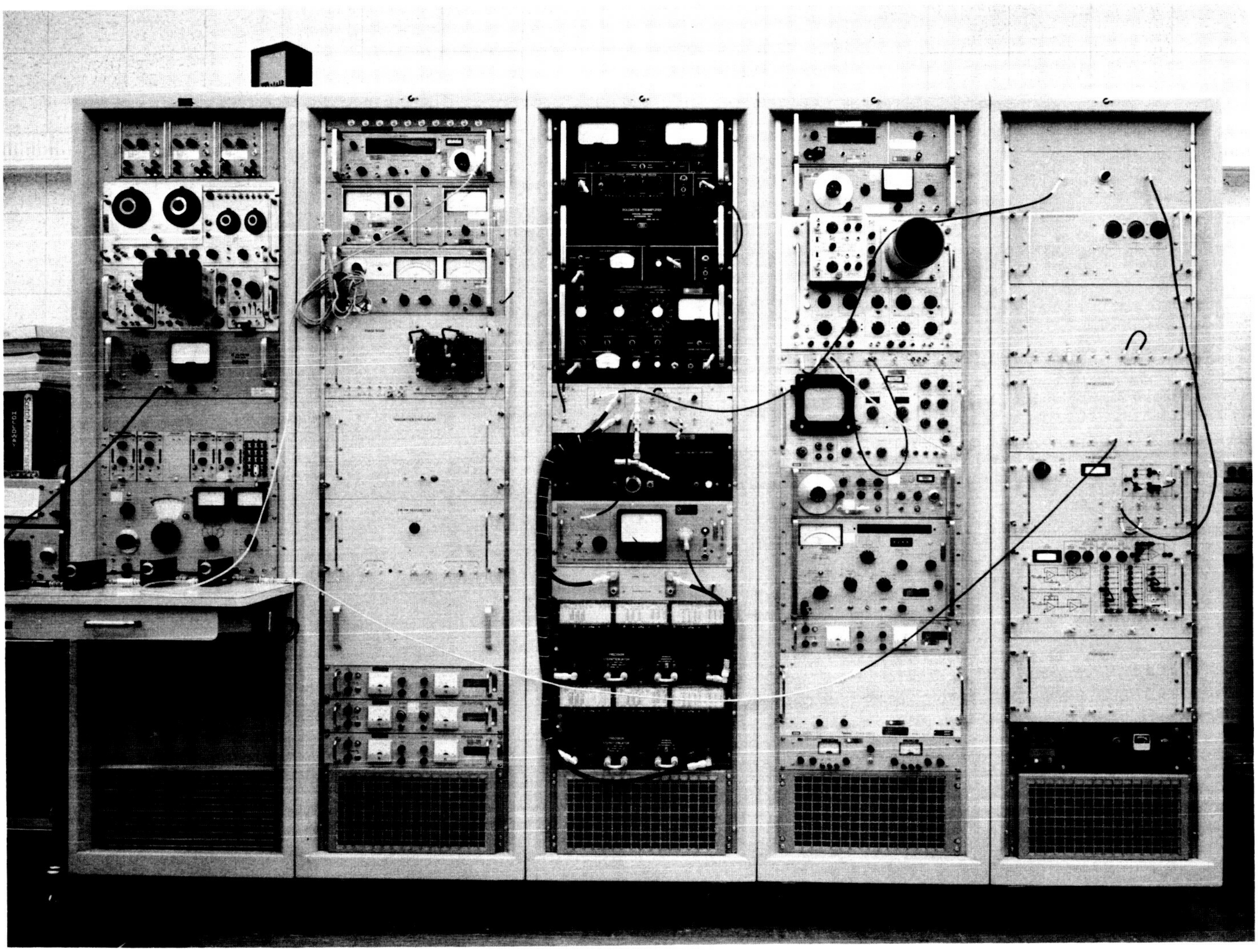


Fig. 2. Test complex

RELAY LINK MODULATION/DETECTION TECHNIQUES

NASA Work Unit 186-68-04-04-55
JPL 384-61301-2-3340

J. C. Springett
D. J. Secor

OBJECTIVE

The objective of this task is to study and analyze modulation, detection, and synchronization techniques applicable to the transmission of telemetry from a landed planetary capsule to an orbiting or flyby parent spacecraft. The data rates that might be employed by a relay link could range anywhere from a few hundred bit/s to many tens of thousands of bit/s, depending upon a large number of design parameters and the type of information to be transmitted. One outstanding problem is that of RF carrier frequency uncertainty due to transmitter drift, doppler, and doppler rates. This could significantly affect the choice of a receiver/detector design, depending upon whether low or high data rates are being considered. Another outstanding problem, which is more or less independent of data rate, is that of bit synchronization in the detector. To solve these problems, all types of modulator/detector pairs are being investigated including PM and FM. Special emphasis is being given to bit synchronization techniques.

THEORETICAL MODULATION STUDIES

Single-sideband phase modulation (SSB-PM) and single-sideband frequency modulation (SSB-FM) are being studied for possible application to capsule relay telemetry links in order:

(1) To relax some of the constraints imposed on DSB modulation approaches when a swept acquisition RF loop (automatic phase control receiver) is used.

(2) To make maximum use of the available RF bandwidth that may be restricted by channel allocation and/or RF receiver design.

The studies are intended to establish:

(1) Spectral characteristics of SSB-PM and SSB-FM signals.

(2) Signal-to-noise performance of an SSB-PM and SSB-FM receivers.

(3) Problems associated with the implementation of SSB-PM and SSB-FM systems.

The form of the modulated signal for either SSB-PM or SSB-FM, expressed in complex analytic form, is given by

$$\underline{S}(t) = \exp\left\{\alpha\left[X(t) + j\hat{X}(t)\right]\right\} \exp(j\omega_0 t) \tag{1}$$

where X(t) may be any low-pass periodic or aperiodic function possessing no singularities on $-\infty < t < \infty$, $\hat{X}(t)$ is its Hilbert transform, ω_0 is the carrier frequency, and α is a constant. For SSB-PM, Eq. (1) is exact. For SSB-FM, we must replace X(t) by $\int_{-\infty}^{t} y(t)dt$, where y(t) is the actual modulating signal.

Analog Hilbert-Transformer

A simulation of SSB-PM utilizing a delay-line Hilbert transformer has been completed. The delay-line Hilbert transform is designed to operate on analog signals, whereas previous Hilbert transforms operated on digital signals.

Analog delay lines have been used to build an analog Hilbert Transformer (HT). The laboratory setup is shown in Fig. 1 and the test results in Fig. 2.

Note that f(t) had to be delayed in order to display all waveforms simultaneously.

SSB-PM Modulation Studies

The SSB-PM modulator and demodulator have been implemented as shown in Fig. 3.

Measured spectra and waveforms agreed very closely with the theoretical predictions. Noise testing will make use of the RF test console.

Clock Recovery Loop Studies

Figure 4 shows a delay clock loop that is being studied for recovery of clock of subcarrier reference signals. Although the binary input to the loop does not directly contain a clock component, this technique can be used to generate the desired clock signal.

ANTICIPATED PROGRESS DURING NEXT PERIOD

Noise testing of the single-sideband PM system will be completed by October 1967. The performance analysis of the clock recovery loop will be completed and experimented verification will be started.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

JPL SPS Contributions

1. Springett, J. C., "On the Spectrum of Single-Sideband Frequency Modulation by Normal Noise."

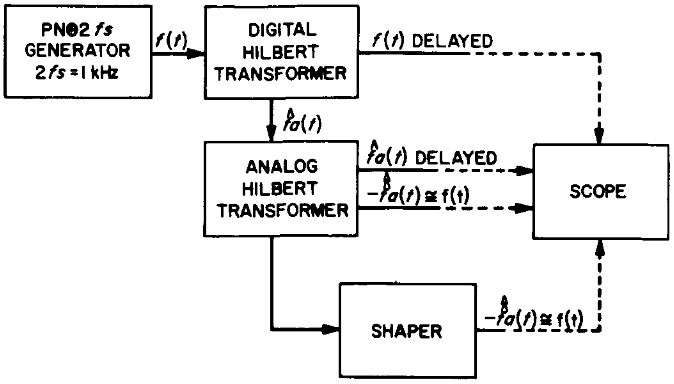


Fig. 1. Laboratory setup

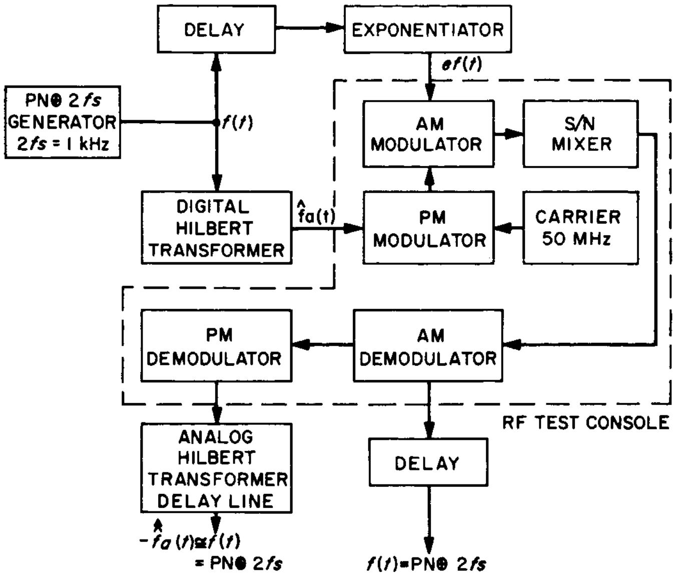


Fig. 3. SSB-PM modulator and demodulator

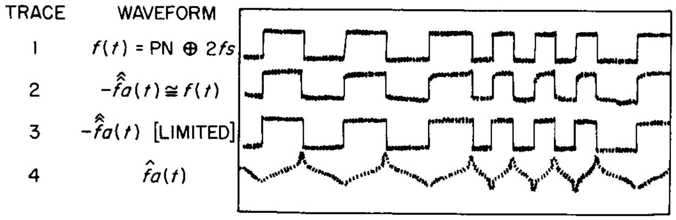


Fig. 2. Laboratory waveforms

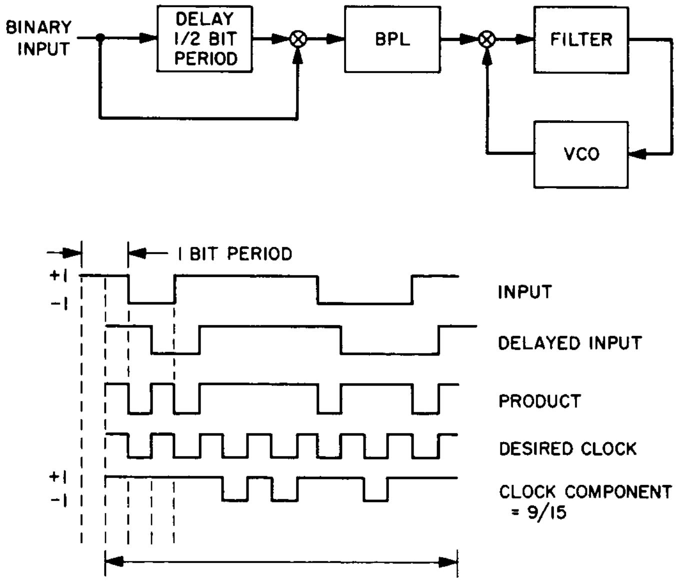


Fig. 4. Delay clock loop

CAPSULE DIRECT-LINK ANTENNA STUDY
NASA Work Unit 186-68-04-06-55
JPL 384-61501-2-3330

K. E. Woo

OBJECTIVE

The purpose of this task is to develop a series of S-band, low-gain, circularly polarized, high-impact antennas for planetary capsule use. The present design objectives are as follows:

Impact Load: 10,000 g imparted into antenna mounting structure

Gain: 4 to 8 dB

Coverage: Hemispheric, half-power beamwidth ≤120 deg.

Ellipticity: < 6 dB within ±60 deg from beam axis

Input VSWR: < 1.2 at 2295 ±5 MHz

< 1.3 at 2115 ±5 MHz

Power Handling Capability: 100 to 500 W

LOW-GAIN HIGH-IMPACT ANTENNAS

During the third and fourth quarters of FY 1967, two antennas (Archimedean spiral, rectangular cup) have been modified to survive indirect impacts of 10,000 g. Two other antennas (square cup, crossed-slot) have been designed and are being ruggedized to sustain high impacts. The following is a brief description of the progress made in developing these antennas.

Cavity-Backed Spiral Antenna

By filling the cavity with low-loss foam and then bonding the circuit board to the foam, this antenna (Fig. 1) has survived an indirect impact of 10,000 g. There has been no appreciable change in the electrical performance of the antenna as the result of the impact, as shown in Table 1.

Table 1. Electrical performance of cavity-backed spiral antenna

Characteristics at 2298 MHz	Before impact	After impact
Gain, dB	4.2	4.2
Half-power beamwidth, deg	88	88
Maximum ellipticity within ±60 deg from beam axis, dB	3.2	3.2
Input VSWR	1.32	1.32

Further work to improve the gain and ellipticity of the antenna is being planned.

Rectangular Cup Antenna

The previously reported rectangular waveguide radiator with a slanted feed (Fig. 2) has been ruggedized. The high-impact model (Fig. 3) of the antenna is made up of a ruggedized rectangular cup with the slanted feed completely imbedded in a low-loss foam. The antenna has survived an indirect impact of 10,000 g without appreciable change in the electrical performance, as shown in Table 2.

Table 2. Electrical performance of rectangular-cup antenna

Characteristics at 2298 MHz	Before impact	After impact
Gain, dB	7.0	7.1
Half-power beamwidth, deg	72 (min)	71 (min)
Maximum ellipticity within ±60 deg from beam axis, dB	3.0	3.0
Input VSWR	1.70	1.68

The beam shape of the antenna is primarily a function of the cross-sectional dimensions of the cup. The half-power beamwidth of the present model varies from a maximum of about 88 deg (occurred at the cut along the narrow dimension) to a minimum of 72 deg (occurred at the cut along the wide dimension). The possibility of adjusting the beam shape (by adjusting the cup dimensions) makes this antenna versatile in beam-shaping applications.

Square-Cup Antenna

This antenna (Fig. 4) is composed of a square cup with a slanted feed. The phase difference required for circular polarization between the orthogonal rectangular modes excited by the feed is obtained by introducing metallic ridges in the

cup as shown. The electrical performance of the antenna is similar to that of the rectangular-cup antenna except that a nearly circularly symmetric beam is achieved. A circularly symmetric beam is desirable for most capsule applications. This antenna is being ruggedized to sustain high impacts.

Crossed-Slot Antenna

The breadboard model of this antenna (Fig. 5) has been made. Electrical measurements show that the antenna has a maximum ellipticity of about 6 dB over a beamwidth of about 170 deg (within ±85 deg from the beam axis) and an input VSWR of about 4. 0. The antenna will be modified for improved electrical performance and for surviving high impacts.

During the fourth quarter of FY 1967, all the effort has been directed toward supporting the CSAD program. Six similar direct link antennas (square-cup type) and one relay link antenna (coaxial-cavity type) are under intensive development for use in the feasibility model of the 1971 probe. Some investigations of the impact limiter and boom interference on antenna patterns were also conducted.

During the first and second quarters of the FY 1968 the CSAD antennas will be completed and delivered, and the other antennas will be further studied and improved. Other new antennas found to have merits will also be added for development.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Woo, K., "High Impact Antenna Study: Rectangular Cup Radiator," SPS 37-43, Vol IV, pp. 386-388, February 28, 1967.

2. Woo, K., "High Impact Antenna Study: Rectangular Cup Radiator, Part II," SPS 37-44, Vol. IV.

3. Woo, K., "High Impact Cavity-backed Spiral Antenna," SPS 37-45, Vol IV.

ANTICIPATED PUBLICATIONS

None.

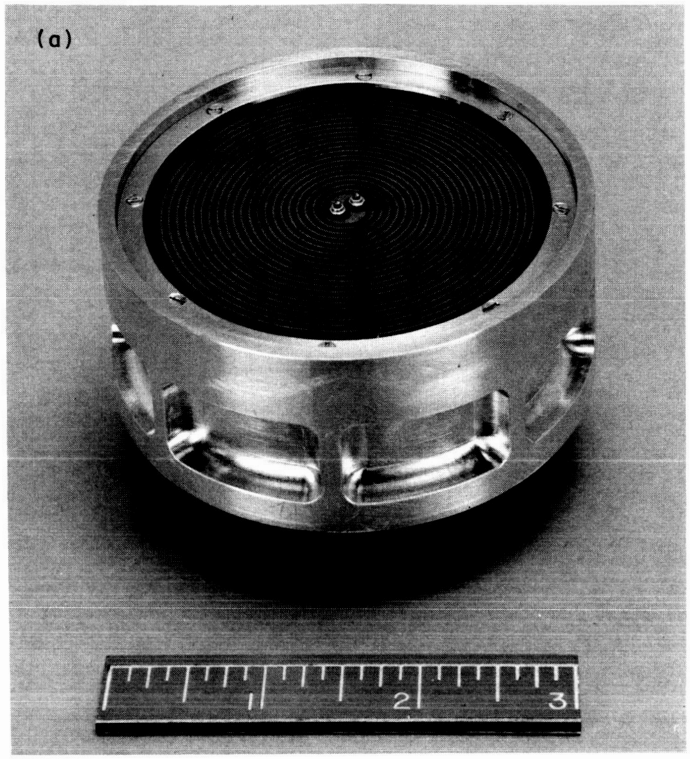


Fig. 1a. High-impact cavity-backed spiral antenna, exterior

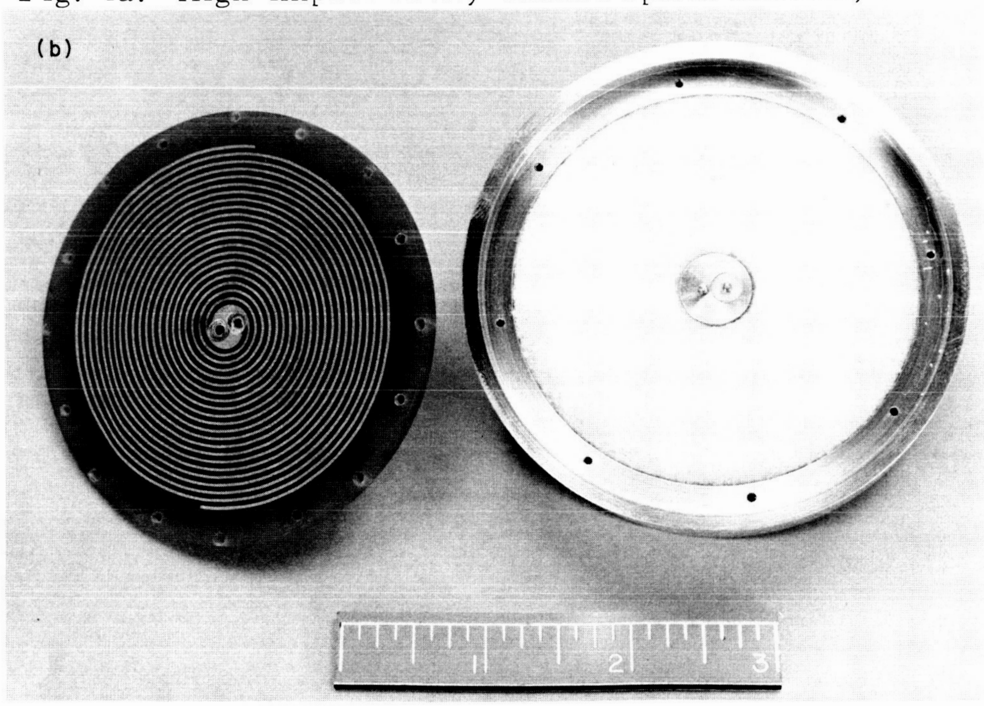


Fig. 1b. High-impact cavity-backed spiral antenna, interior

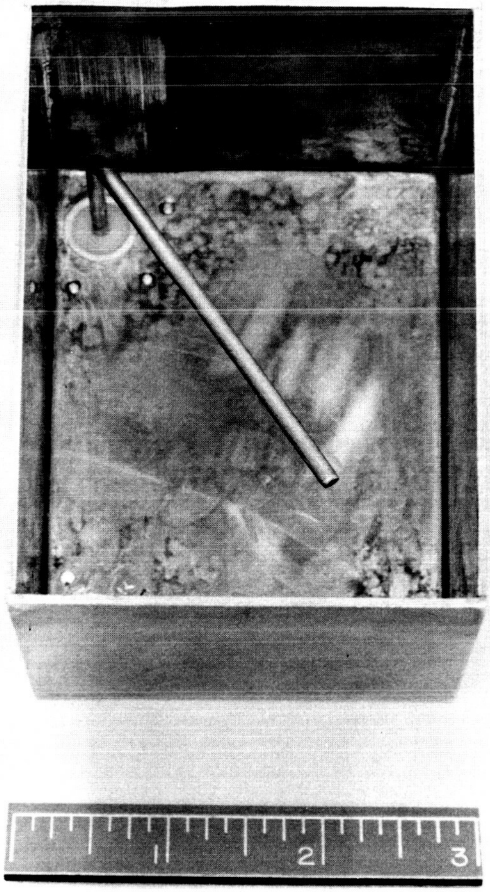


Fig. 2. Rectangular-cup antenna

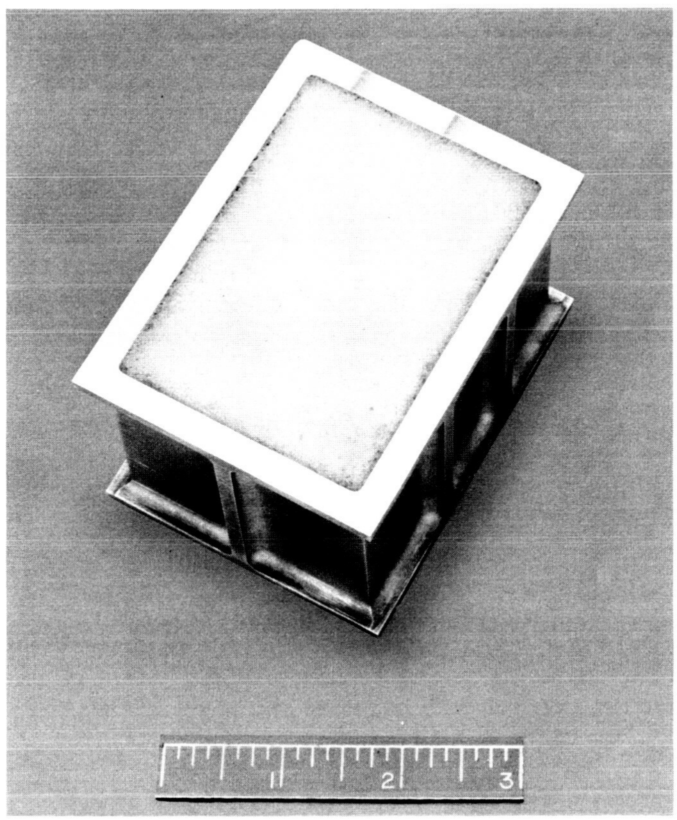


Fig. 3. High-impact rectangular-cup antenna

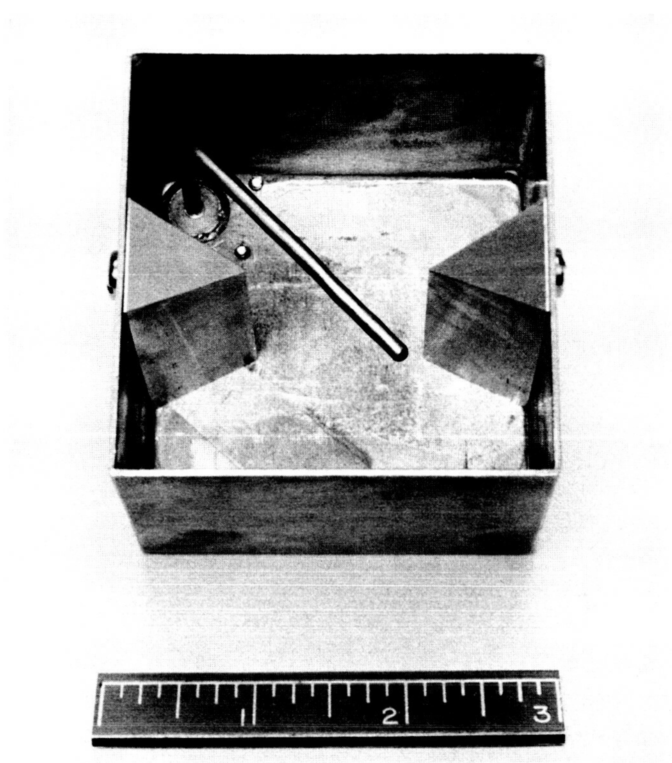


Fig. 4. Square-cup antenna

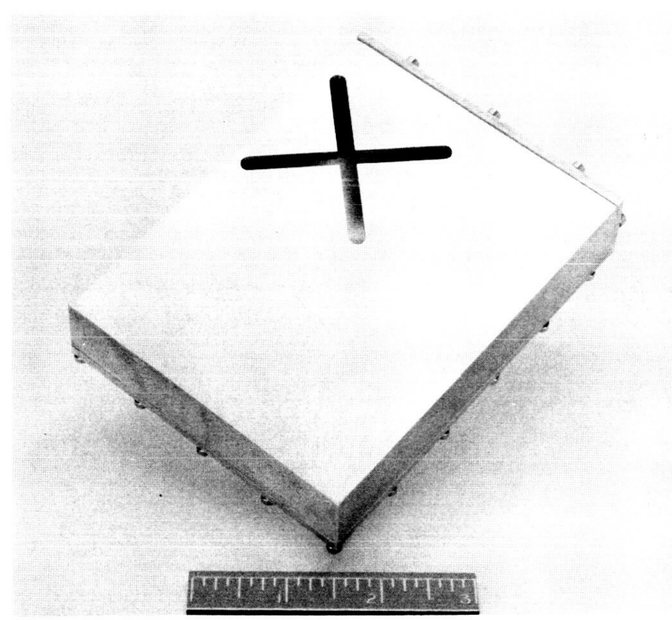


Fig. 5. Crossed-slot antenna

CAPSULE RF RELAY

NASA Work Unit 186-68-04-08-55
JPL 384-63101-2-3360
A. G. van der Cappellen

OBJECTIVE

The objective of this work unit is the required advanced development and engineering to produce a prototype UHF transmitter and a breadboard receiver for a capsule to bus RF relay system. The 13-W, 400-MHz transmitter presently under development is being designed to operate during capsule cruise and entry modes, and thus will be sterilizable and will operate in an atmosphere of arbitrary composition and pressure. The modulation will be bi-level FSK at 500 bit/s. The long-term goals are higher transmitter power (up to 100 W) and higher bit rate capability (up to 200 kbit/s).

13-W TRANSMITTER

The 13-W transmitter is being developed in-house taking advantage of much of the design of the S-band transmitter being developed under "Low-Data-Rate Telemetry RF Systems Development," NASA Work Unit 150-22-17-06-55. The relay transmitter consists of the VHF portion of the S-band unit (191 MHz, 20 W point) which is retuned to 200 MHz and followed by a varactor doubler. High-shock-level survival is not a relay requirement. The 13-W relay transmitter will, however, survive a 10,000-g shock because it is patterned after the S-band unit.

The transmitter, with the exception of the final doubler, has passed the 10,000-g shock test. The entire transmitter has passed the thermal vacuum test (-10 to +75°C) and a sterilization heat test (145°C for 15 h), and has an efficiency of 34%.

A study was initiated to analyze and compare various mechanizations of large and small deviation frequency modulators. However, because the low rate (500 bit/s is a definite, immediate goal, it was decided to concentrate on the relatively small-frequency-deviation requirement ($\simeq$25 kHz at 400 MHz) for the low-rate system. A single oscillator, a VCXO, was chosen. Analysis of FSK spectra has shown:

(1) The spectra for discontinuous phase FSK fall off as $1/f^2$ for large f.

(2) The spectra for continuous phase FSK fall off as $1/f^4$ for large f.

Therefore, in a system with small relative difference frequency, the use of a continuous-phase FSK oscillator would be beneficial to minimize the cross talk. This design is also the simplest to incorporate into the present transmitter. A breadboard modulator has been built and evaluation is under way.

RECEIVER

The receiver will be used for transmitter evaluation tests and for link performance tests. A receiver that will satisfy present requirements and yet be easily adaptable to anticipated future requirements is shown in Fig. 1. It is being assembled from commercially available modules and in-house built circuits.

The receiver will have both separate channel detection and conventional frequency discriminator detection capability. It is planned to test the transmitter and receiver with a breadboard telemetry modulator and demodulator in mid-FY 1968 and to complete the prototype transmitter and breadboard receiver design by the end of FY 1968.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

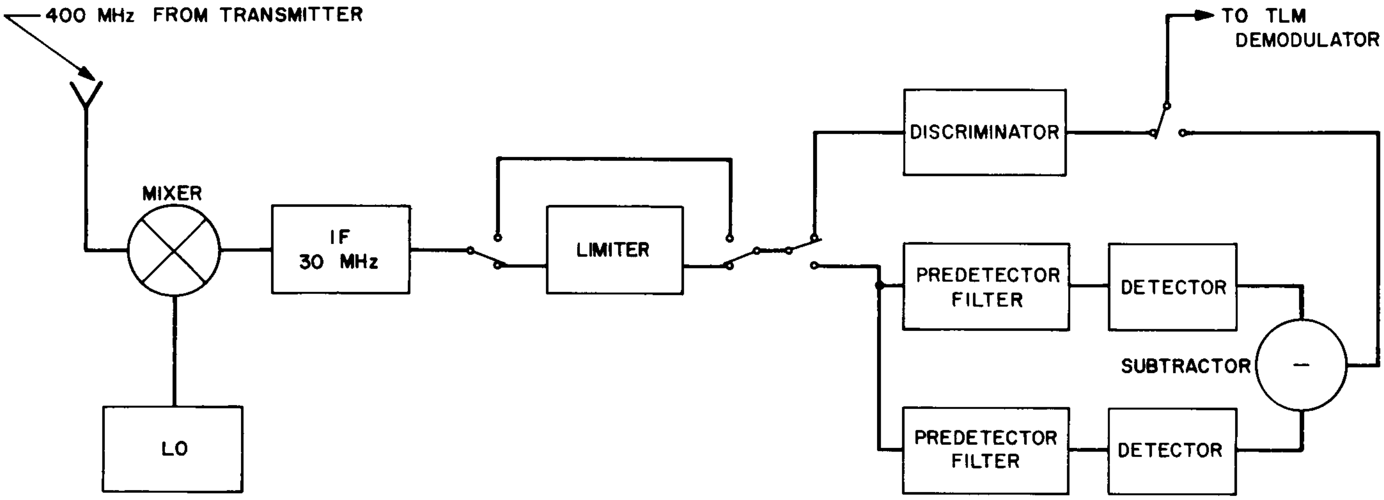


Fig. 1. Breadboard receiver

RF POWER AMPLIFIERS
NASA Work Unit 186-68-04-09-55
JPL 384-63401-2-3360

L. J. Derr
R. S. Hughes
R. Plummer

OBJECTIVE

This effort is a continuation of the FY 1965 effort as presented to NASA Headquarters on October 15, 1964. The overall plan was modified at JPL on September 27, 1965, and has been reviewed for NASA personnel (at JPL) semiannually starting with April 15, 1966. The objectives are as follows:

(1) Develop S-band RF power amplifiers for approved, spaceflight missions.

(2) Increase the available RF power levels consistent with projected spacecraft needs and capabilities (currently estimated to be 20 to 500 W for the Voyager and Advanced Planetary programs).

(3) Improve the efficiency, stability, reliability, and operating life of RF power amplifiers.

(4) Develop efficient heat dissipation techniques for RF power amplifiers.

(5) Remain abreast of power amplifier technology so as to be capable of efficient in-house development and contractor direction.

ESFA DEVELOPMENT (JPL CONTRACT 951105)

The purpose of this contract is to develop variable power (20 to 100 W and 100 to 500 W) RF amplifiers employing a hybrid RF circuit design, electrostatic focusing, and a radiation-cooled collector system. The contract is divided into four phases:

(1) Development of a 20 to 100-W tube.

(2) Production of five 20 to 100-W tubes for life test.

(3) Development of a 100 to 500-W tube.

(4) Production of five 100 to 500-W tubes for life test.

This contract was assigned to Eitel McCullough on May 10, 1965. Due to the relatively undefined domains of electrostatic focusing, extended interaction circuitry and radiative cooling means phase I has consumed more development time than originally expected. Although specified performance levels have been reached in the areas of gain (30 dB) and bandwidth (30 MHz), the single parameter of efficiency has caused a series of unplanned development iterations during this period. A level of

37% has been reached, whereas the specified efficiency value was 45%. In support of this work, computer studies of beam behavior have been made by the vendor, and early performance limits were tentatively explained by the study results. A subsequent prototype tube, built according to the computer-suggested design, did not, however, produce further improvements in efficiency. The prototype tube was then studied in an operating condition inside a special beam analyzer system. It was discovered that beam divergence due to RF modulation was not as great as that predicted by the computer. Thus, the RF coupling coefficient was suboptimal. The vendor is proceeding to modify the output circuit in accordance with the beam analyzer results. It is expected that improvements in tube efficiency will result from these modifications. The experimental tubes used thus far have had water-cooled collectors. Two heat-radiating collector assemblies have been tested in vacuum test tubes and have demonstrated 80% heat radiation efficiency. If this performance can be maintained in a complete ESFA, the specified 60% heat radiation efficiency for the complete tube should be achieved. Phase I is scheduled for completion in January 1968. Contract obligations to date are $385,000.

HIGH-EFFICIENCY TWT DEVELOPMENT (JPL CONTRACT 951299)

This development seeks an advancement in efficiency in traveling-wave-tube design. The development goal is 55% at 100 W RF output. The tube will be conduction-cooled, magnetically focused, and will employ a newly developed helix design. The contract was signed with the Watkins-Johnson Company April 12, 1966, and is divided into two phases:

(1) Development of the 100-W tube.

(2) Production of five 100-W tubes for life test.

The goal of phase I is to develop beyond the present state of the art the RF efficiency of traveling wave tubes which are capable of producing a power output of 100 W at S-band frequencies. It was intended that this program would employ designs which had been created on other government-sponsored efficiency studies. When this contract was initiated, the concept of using a dual-helix design was selected by JPL as the most promising means of achieving the highest TWT efficiency.

Much of the early part of the program has been used to perfect the thermal design of the 100-W space tube and involved only standard electronic circuitry. With a single helix the 100-W level has been reached with an RF efficiency as high as 35%. During this period the tube encapsulation has been developed, and high-efficiency designs have been started. The first tube employing the dual helix was constructed and tested. A problem was discovered in this design when used at high RF power levels. Interception of the high-velocity beam produces secondary electrons which flow from one helix to the next. These secondaries can reduce the efficiency by interfering with the primary beam and by increasing the helix dissipation if they are collected at a high potential. The magnitude of this problem is not known, but it is presently being investigated.

A collector cooling investigation is being conducted in-house, since techniques presently used for flight tubes provide inadequate heat conduction for the 100-W operation. Clamping, soldering, and use of special materials and shapes are being investigated.

The growing technical task of phase I has caused JPL to modify the program to include other techniques which show promise of high efficiency for TWTs. The concept of phase-stepping will be employed next. Phase I has now been extended by seven months to allow further research work. If sufficient funds are available, the added effort will be funded in FY 1968 for $95,573, which brings the total for phase I to $264,773.

JPL LIFE TEST FACILITY

This work unit provides the cognizant engineering direction and guidance necessary for the design and implementation of the JPL life test facility. This facility will house space simulating chambers, automated data collecting systems, and all necessary electronic support and monitoring equipments.

The building will be constructed and maintained as an appendage of the JPL Environmental Test Laboratory, but it is independently devoted to the support of advanced telecommunication equipment life studies. Its design is specialistic to long-endurance RF life testing. The building costs are being financed from FY 1968 minor construction funds ($100,000 from Voyager NASA Work Unit 818-11-06-02-25 and $150,000 from ORAD project office burden).

During this period full authority for the building construction has been received at JPL. An architect and engineering firm has been selected. Preliminary plans for the building have been submitted by the architect and engineering contractor for JPL's comment. The design work will be completed by mid-July 1967 and the building construction is scheduled to be completed by February 1968.

TUBE EVALUATION PROGRAM

The evaluation of commercially available power amplifiers serves two main purposes:

(1) To advance our knowledge, thus improving our capability both for in-house development and in directing the outside development contracts now under way.

(2) To determine the applicability of each amplifier to future NASA programs.

In the previous seminannual report it was stated that the Litton ESFK, model L-3910B, failed just prior to beginning its life test and was therefore returned to Litton for analysis of the failure. Litton's findings were not conclusive, and they could only speculate as to what caused the failure. They offered to rebuild the tube for $3,000 on a best-effort basis. Thus, we had no guarantee that the rebuilt tube would be worthy of life testing, and therefore the task was terminated.

Brief, electrical tests were performed on three amplitrons, Raytheon model QKS 1300. Generally, the test results compared favorably with the data furnished by Raytheon. However, one tube failed during the tests and was returned to Raytheon.

Raytheon determined that the tube was a "leaker" and has replaced it. The two tubes which passed the initial electrical tests are now being life tested. The life test on the third tube will commence after electrical tests are completed.

Two Watkins-Johnson TWTs, model WJ 274-1, and life test power supplies were received. Extensive electrical evaluation tests being performed on the tubes are nearing completion. A brief comparison between the WJ and JPL electrical data is shown in Table 1. Environmental tests will begin in July. Assuming the tubes pass the environmental tests, they will be placed on life test early in FY 1968.

The data recording system for the radio life test area, mentioned in the last semiannual report, has been installed and is now in operation. A similar system, costing $13,000 has been purchased for use during electrical evaluation tests. This system is being used for some of the electrical testing of the WJ 274-1 TWTs. The use of these systems has resulted in a definite improvement in the quality of the test data with a significant reduction in test time required.

PUBLICATIONS DURING THIS REPORT PERIOD

Contractor Reports

1. Monthly Progress Reports 19 through 24, Eitel McCullough (JPL Contract 951105).

2. Quarterly Report 1, Eitel McCullough (JPL Contract 951105).

3. Monthly Progress Reports 9 through 14, Watkins-Johnson Company (JPL Contract 951299).

4. Quarterly Reports 1 and 2, Watkins-Johnson Company.

ANTICIPATED PUBLICATIONS

JPL SPS Contributions

Intermittent Articles in SPS Vol. IV.

Contractor Reports

1. Monthly Progress Reports 25 through 30, Eitel McCullough (JPL Contract 951105).

2. Quarterly Reports 2 and 3, Eitel McCullough (JPL Contract 951105).

3. Monthly Progress Reports 15 through 20, Watkins-Johnson Company (JPL Contract 951299).

4. Quarterly Reports 3 and 4, Watkins-Johnson Company (JPL Contract 951299).

Table 1. Comparison of WJ and JPL electrical test data

Parameter	WJ 274-1, S/N 29		WJ 274-1, S/N 31	
	WJ	JPL	WJ	JPL
Filament supply voltage, V	3.5	3.5	3.75	3.75
Filament current A	0.81	0.81	0.87	0.87
Anode supply voltage, V	180	180	150	150
Anode current, mA	0.13	0.13	0.35	0.33
Helix supply voltage, V	1645	1645	1640	1640
Helix current, mA	4.2	4.8	5.1	5.6
Collector supply voltage, V	1175	1175	1155	1155
Collector current, mA	49.6	51.6	47.8	49.1
Frequency, GHz	2.3	2.295	2.3	2.295
RF input, W	0.084	0.084	0.041	0.041
RF output, W	23.3	24.3	24.0	24.5
Overall efficiency, %	34.2	34.1	35.9	35.5

ADVANCED SPACECRAFT TELECOMMUNICATION SYSTEMS

NASA Work Unit 186-68-04-11-55
JPL 384-63201-2-3360

M. A. Koerner
D. W. Boyd
W. E. Ackerknecht
D. Stott
M. K. Tam*

OBJECTIVE

The objectives of this work unit are to provide the telecommunication system analysis and synthesis for advanced spacecraft missions and to coordinate the R/AD work units which relate to the development of the system elements such as transmitters, receivers, modulators, demodulators, encoders, and decoders.

RADIO SUBSYSTEM ANALYSIS

Effect of Distortion of Ranging Signal in Turnaround Ranging Channel on Ranging System Margin and Accuracy

Existing analysis of the ranging system assumes that the ranging signal is not appreciably distorted by the turnaround ranging channel. The objective of this analysis is to determine the effect that distortion of the ranging signal in the spacecraft RF receiver, the channel coupling, the output of the spacecraft RF receiver to the spacecraft transmitter, the DSN RF receiver, and the DSN ranging receiver has on ranging system margin and accuracy.

Distortion of the ranging signal in the spacecraft RF receiver, the channel coupling the output of the spacecraft RF receiver to the spacecraft transmitter, the DSN RF receiver, and the DSN ranging receiver will alter the cross-correlation between the received ranging signal and the signal generated by the DSN ranging receiver. The analysis required is (1) to evaluate the effect of the distortion on these cross-correlation functions and (2) to evaluate the effect of distorted cross-correlation functions on ranging system margin and accuracy.

A major portion of the mathematical analyses had been completed as of the last semiannual progress report. During this reporting period, the principal emphasis has been placed on the completion of the remainder of the mathematical analysis required for an arbitrary ranging code and the application of these results to the special case where only a square wave clock signal is transmitted through the turnaround ranging channel.

*Contract associate.

For the case where the ranging code has arbitrary form, the principal parameter of interest is the cross-correlation between the output of the limiter in the spacecraft transponder coupling channel and reference signals generated by the DSN ranging receiver. The equation previously derived for this cross-correlation has been manipulated into a form amenable to numerical evaluation for ranging codes of very long period. For comparison with general results, an equation has been derived for this cross-correlation when the spacecraft RF receiver and coupling channel do not distort the ranging signal. The asymptotic behavior of this cross correlation has been derived for $\eta_1 >> 1$ and $\eta_1 << 1$ where η_1 is the ranging signal-to-noise ratio at the input to the limiter in the spacecraft transponder coupling channel in the absence of ranging signal distortion.

For the case where the ranging code is a square wave the parameters of interest are the incremental loss of clock power and the clock phase shift in the system. Both the mathematical analysis and computer programs required have been completed. The behavior of the incremental clock power loss and the clock phase shift on the turnaround channel has been determined when the effective transfer function of the spacecraft transponder RF receiver and coupling channel is either

$$H1(1;s) = \left(1 + \frac{s}{\omega_o}\right)^{-1} \tag{1}$$

or

$$H1(1;s) = \left(1 + 2\,\Psi \frac{s}{\omega_o} + \frac{s^2}{\omega_o^2}\right)^{-1} \tag{2}$$

and the DSN RF receiver and DSN ranging receiver do not distort the ranging signal.

The most significant results of these calculations are the behavior of the incremental clock power loss and the clock phase shift as a function of η_1. Numerical results have been obtained for both transfer functions considered. For the single-pole transfer function, noise-bandwidths of 0.5 to 2.5 times the symbol rate of the square wave were examined. For the double-pole transfer function, the same range of noise bandwidth was examined for damping factors of 0.7 to 1.0. In both cases the signal-to-noise range considered was -30.0 to +20.0 dB. For the single-pole filter with the 1.5-MHz noise bandwidth presently planned for the Mariner Mars 1969 transponder, the numerical results show a 6.8-deg change in the phase shift of the clock from weak to strong signal and a 1.5-dB additional loss in system margin at weak signal levels. The numerical results also indicate that performance can be substantially improved by using a two-pole filter with 0.7 damping and the same noise bandwidth. In this case, the phase shift variation is 0.8 deg and the additional loss in system margin is 0.5 dB.

From the preceding results it is evident that the proper choice of the transfer function for the spacecraft RF receiver and coupling channel make the clock phase shift relatively insensitive to changes in η_1. As any uncalibrated phase shift of the clock signal will introduce an error in range measurement of approximately 0.86 m/deg, such insensitivity is a very desirable characteristic. Further analysis has shown that a class of physically realizable transfer functions exist which will make the clock phase shift independent of η_1. For example, the transfer function

$$H1(1;s) = \frac{1 - \exp^{(-sT)}}{T_s}$$

where T is less than 1 μs, when used with the DSN Marking I ranging system, has this property.

SYSTEMS METHODOLOGY

Reliability

The long-range objective of this task is to develop methodology for (1) the realistic assessment of telecommunication system reliability and (2) synthesis of reliable telecommunication systems. This is largely accomplished through a contract with Tam Research Associates which was reactivated in April 1966. This contract covers an 18-mo period at a labor cost of $36,000.

The preliminary draft of a consolidated report covering the past study efforts on system reliability prediction techniques for telecommunication system synthesis has been completed. This report reviews the historical background of the reliability study program and discusses in sufficient detail the mathematical development of such topics as measure of uncertainty of reliability prediction, probability of reliability improvement, and sampling distribution for component part failure parameter (for experimental identification of a probability distribution function for the failure parameter).

Communication System Performance and Cost Analyses

The investigation of telecommunication system performance versus the average cost required to achieve a given mission has been continued. As has been noted, the increase in power-gain product of spacecraft communication system increases the cost of the radio subsystem directly. However, this will also raise the performance level of the communication system and reduce the probability of communication failure and will, as a consequence, effectively lower the average mission cost. In this particular study, the total average mission cost as a function of power-gain product is obtained and, the optimum power-gain product at which the cost function is at the minimum is determined graphically. This relationship is demonstrated first by a hypothetical Mars-distance mission, followed by a long-distance mission with a nominal power-gain product 20 dBm over that of the former. Finally, similar analysis reflecting the loss of scientific measurement capacity as a result of the payload weight increase for higher margin of performance is also given. In addition, a weighting function for subjective adjustment according to the current status is introduced. The results of this study have been summarized in a report entitled Performance Margin and Cost Tradeoff for Spacecraft Telecommunication System Design.

Tolerances of Communication System Parameters.

In supporting the performance-cost tradeoff study for spacecraft telecommunication system design, a task whose objectives are to establish a uniform meaning of tolerance and to study the propagation of tolerances has been initiated during this reporting period. An interim report which defines the various technical terms most frequently used in relation to tolerance and measurement has been prepared. This report also includes suggested methods and procedures for establishing the tolerance limits of individual system components and the overall system.

A least square curve fit using orthogonal polynomials was reprogrammed for greater utility by changing to Fortran IV, changing formats, and adding residual plots. This program was used to demonstrate how instrumentation errors for the digital antenna pattern (DAP) generator could be reduced by approximately 0.5 dB. It is expected that the program will be changed to include plotting of the auto-correlation function of the residuals as a further aid in evaluating the degree of the polynomial that should be used.

To further the handling of instrumentation errors, conditional probabilities were analyzed to describe instrumentation errors utilizing the auto-correlation function. For the simple case, the conditions that zero and full-scale residuals are specified (condition state) to be zero. As expected, the σ error becomes zero at the end points and progressively worsens in between. When other than zero, the mean error has a centralizing effect in addition. The general case for additional conditional states corresponding to calibration points on the scale was analyzed. These analyses are expected to be applied to d'Arsenval meter errors and slide-wire type instrument measurement errors which will aid in the interpolation and specification of errors between calibration points.

This task has been supported through the contract with Tam Research Associates mentioned under reliability.

Minimum Cost Telecommunication Design Study

The objective of this study is to perform analysis to determine telecommunication systems which are designed and synthesized for minimum total mission costs rather than minimum spacecraft weight. It is expected that this study will be conducted by a contract. Funds were set aside to be obligated during the fourth quarter of FY 1967, but this was not accomplished. Some work was accomplished on a Statement of Work, but completion was delayed. It is felt that great care must be exercised in writing the Statement of Work, or the objectives will not be met.

It is hoped that funds will be available in FY 1968 to continue this work.

LONG-TERM PLANNING

Optimum Spacecraft Antenna and Power Amplifier Classes To Meet Future Mission Requirements

The objective of this task is to determine optimum spacecraft antenna and power amplifier classes to meet future mission requirements so that R/AD work units provide the necessary equipment.

During the reporting period work has progressed in two stages:

(1) Determination of weight functions for dependent subsystems.

(2) Development of an analysis for determining optimum antenna size and transmitter power.

Spacecraft subsystems whose weights were considered dependent on antenna gain or transmitter power have been defined as:

(1) High-gain antenna.

(2) Antenna pointing system.

(3) Attitude control system.

(4) Power amplifier.

(5) Primary power source.

(6) Secondary storage battery.

Weight functions for the first three subsystems have been determined as functions of antenna gain, and the last three subsystems have been determined as functions of transmitter power. It should be pointed out that these weight functions are approximations, since not all influencing parameters could be considered in sizing the subsystems for a general class of mission.

The second portion of the task, analysis to determine optimum antenna and power amplifier size, was carried out graphically using the previously defined weight functions. To simplify the graphical presentation of results, the number of mission parameters was reduced to two: required gain-power product and power source specific weight. The power source specific weight was evaluated as a function of the type of prime power source, heliocentric range, and maximum battery discharge time.

An effort is being made to define more accurately the subsystem weight functions. Also, a hypothetical set of planetary missions is being defined. The application of the described results to this set of missions will provide a guide to future antenna and power amplifier requirements.

SPACECRAFT ANTENNA SUBSYSTEM ANALYSIS

Tracking Systems

The objective of this task is to study the basic techniques presently used for antenna tracking of RF sources. The emphasis of the task is on the analysis and synthesis of signal processing techniques suitable for spacecraft mounted tracking antenna systems.

Future missions have indicated the need for larger antennas, which will undoubtedly require spacecraft tracking antenna systems. This work is just beginning and will be a continuing in-house effort.

Introductory work was begun by examining the Apollo LEM and CSM tracking antennas and their respective problems. This work is being expanded to more general tracking systems.

TELEMETRY SUBSYSTEM ANALYSIS

Relay Link Telemetry

The objective of this work is to perform analysis on problems related to the choice of an efficient telemetry system for communication between a planetary capsule and the spacecraft from which it is separated.

During this reporting period, considerable attention was given in coordinating the R/AD efforts for the Relay Link Telemetry Task. A list of candidate systems was drawn up for which system performance estimates were made as well as specific detailed analyses.

Specific analyses were undertaken and completed for:

(1) PCM/FM discriminator detector with output filtering.

(2) Comparison of coherent PSK and noncoherent FSK systems.

(3) Spectral characteristics of binary FSK with continuous and discontinuous phase transitions.

(4) FSK performance with large uncertainty in carrier frequency.

(5) Using "click" approach developed by S. O. Rice, determination of bit probability of error of FM receivers with discriminator detectors and with large uncertainty in carrier frequency.

Additionally, some attention has been given the bit synchronization problem.

Low-Data-Rate/High-Impact Direct Link Telemetry

The objective of this task is to analyze from a systems point-of-view the low-bit-rate telemetry system that will be used to communicate from a hard-landed planetary capsule to the earth. Special attention will be given to defining system performance objectives and the subsystem functional requirements for meeting the system objectives.

The problem of designing a digital tracking loop for the spectrum analyzer receiver has been considered. The first step in this analysis has been completed. The analysis shows that the optimum compensator is a digital integrator with a variable gain.

The processing and storage requirements in the ground computer of the MFSK system have been analyzed in detail. Calculations for representative parameter values are being prepared. The present MFSK system is deficient in at least two related aspects:

(1) Performance losses caused by the necessary truncation are severe.

(2) Processing time requirements are somewhat larger than would be desirable.

To alleviate one or the other of these problems, consideration is being given to variations of the present system. One possibility would be to use the fast Fourier transform technique for evaluating the necessary correlations and spectra. This technique is based on the Cooley-Tukey algorithm and can yield significant advantage in some cases. However, for the present levels of truncation preliminary analysis indicated that any time advantage (if indeed any exists) is not significant. The P_E performance is the same, independent of which technique is used to evaluate the necessary functions.

Another possibility would be to employ a special purpose spectrum analyzer such as a coherent memory filter. An analysis of the CMF shows that although very reasonable processing times can be obtained, P_E degradation is even more severe with increasing truncation. Its use also poses significant hardware problems so that it will not be considered further.

A major part of this task effort was directed toward telecommunications system analysis support for the new Capsule System Advanced Development (CSAD). As a part of that effort, an evaluation of alternate turnon (checkout) sequences has been completed. For the CSAD it appears that the best checkout sequence would be to monitor lander performance via the spacecraft telemetry system prior to separation.

Work has begun on a study of the effects of multipath. It appears that the Martian surface can be characterized as a specular reflector for the problem of interest. A portion of the computer program necessary to evaluate the effect of multipath has been written and checked out. The programming is about one-third complete.

The problems of antenna selection and antenna placement have been considered briefly. This work will be continued, but will be subordinated to higher priority tasks.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Tam, Man K., "Performance Margin and Cost Tradeoff for Spacecraft Telecommunication System Design," SPS 37-45, Vol. IV, May 31, 1967.

ANTICIPATED PUBLICATIONS

None.

FREQUENCY MULTIPLIER AND CRYSTAL DEVELOPMENT

NASA Work Unit 186-68-04-18-55
JPL 384-67601-2-3360

R. B. Postal

OBJECTIVE

The objective of this work unit is to provide the cognizant engineering effort necessary to monitor contracts (funded by NASA Work Unit 150-22-17-06-55) for the development of a quartz crystal unit and an S-band frequency multiplier. These devices must be capable of surviving a 10,000-g impact and of performing reliably after being subjected to a 135°C heat sterilization process. They are to be used in the S-band solid-state transmitter being developed for hard landed capsules under "Low-Data-Rate Telemetry RF Systems Development," NASA Work Unit 150-22-17-06-55.

X-4 STRIPLINE FREQUENCY MULTIPLIER

As previously reported, Motorola responded to the JPL second solicitation with a bid to develop an X-4 stripline frequency multiplier capable of meeting all the requirements set forth in JPL Statement of Work SW 162-336. The bid was evaluated and a contract for $7,500 was awarded in January under PO BY 331739. The multiplier was delivered to JPL on May 9, 1967. Preliminary evaluation shows the unit to meet all RF specifications at room temperature under static conditions. Environmental testing will begin in July.

HIGH-IMPACT QUARTZ CRYSTAL DEVELOPMENT (JPL CONTRACT 951080)

The purpose of this contract is to develop a high-impact sterilizable crystal for use in the 3- to 5-W S-band transmitter. The vendor, Valpey-Fisher Corporation, has been under stop-work-order since January pending JPL evaluation of PTM units submitted by the vendor and negotiations concerning a change in the development plan for this contract. Of the three crystals submitted in November 1966, only one survived all the environmental requirements of the specification (JPL Spec. 30250-B). The unit also survived 8200-g shock levels but failed at 10,000 g. The remaining crystal units developed excessive phase jitter when subjected to vibration testing. Upon disassembly of one of the units, surface abrasions were found on the quartz resonator. A further examination of the ceramic holders showed high spots in the holder cavity that match the location of the resonator abrasions. This failure is apparently a manufacturing deficiency and can be corrected by careful ceramic grinding and depth measurement techniques.

In general, the change in development plan for this contract involves:

(1) Change in frequency to 31.875 MHz (from 19.125 MHz).

(2) Inclusion of the 10,000-g shock requirement to the specification.

(3) Inclusion of sterilization requirement to the specification.

Negotiations for this phase of the contract have been completed, and contract reviewing is now in process. Contract distribution is expected July 17, 1967. Delivery of ten crystals is scheduled for November 1967. Funds obligated to date are $64,000.

Two additional types of crystals were evaluated at JPL for impact resistance. One group of five TO-5 crystals (Valpey-Fisher) failed the first shock test of 5200 g. Posttest examination of these units showed the resonator to be supported with 0.001-in. ribbon leads rather than directly by the header feedthroughs. All resonators were found to be broken. Nine Midland CR-24 units were also impact-tested with the following results: two units failed at 2500 g, one failed at 5500 g, two failed at 6200 g, and two failed at 7500 g. The remaining two units survived twelve planes of testing through 7500 g. Frequency shifts of the nine units ranged between 0.3 and 50 parts/10^6 per shock.

The high-impact work connected with the development of the X-4 stripline frequency multiplier and high-impact quartz crystal is heavily supported by "High-Impact Communications Subsystems Technology," NASA Work Unit 186-68-04-14-55.

PUBLICATIONS DURING REPORT PERIOD

Contractor Reports

1. Valpey-Fisher Corporation, Report Series 5718, N. Gillin, Monthly Progress Reports for the period January 1, 1967 through June 30, 1967.

ANTICIPATED PUBLICATIONS

1. Contractor Progress Reports.

2. JPL SPS Article.

TELEMETRY MODULATION SYSTEM DEVELOPMENT

NASA Work Unit 186-68-04-19-55
JPL 384-67801-2-3340

N. Burow
C. Carl
A. Couvillon
A. Vaisnys

OBJECTIVES

This work unit consists of three closely related efforts: the development of a prototype multimission telemetry system, the development of a relay telemetry system for the Capsule System Advanced Development, and the investigation of the effect of imperfect bit synchronization on telemetry system performance.

COMPUTER DEMODULATOR

Goals

This task is part of the Multiple Mission Telemetry System (MMTS) effort which was organized to design and develop a mission-independent telemetry system. The goals of this work are to conduct preliminary investigations into system feasibility and performance and to accomplish the integration and testing of a prototype system.

Approach

Shortly after the MMTS concept was generated, work began on the construction of a model of the system to demonstrate its operation and investigate the practical problems of building such a system. A Scientific Data Systems (SDS) model 920 computer was available, but the RF hardware called for in the early conceptual designs was not. It was therefore necessary to "model" the system at audio frequencies, i. e., the 10-MHz bandpass filters were simulated by 100-kHz filters having the same bandwidth. The resulting assembly, which will hereafter be called the baseband breadboard (BBB), very closely duplicates the functions of the "real" system design except that the input signal is the subcarriers plus low-passed noise, instead of a phase-modulated intermediate carrier plus band-passed noise. In a sense, the 10-MHz IF has been replaced in the BBB by zero frequency.

Figure 1 is a diagram of the BBB and the subcarrier and data source. The latter generates square-wave subcarriers modulated (phase-shift keyed) by data bit streams, which can alternate "one-zero", all "ones", or long pseudonoise (PN) code sequences. As shown, the bit timing clock may be coherent or noncoherent with the subcarrier clock. The subcarrier(s) thus generated are linearly added to noise in a signal/noise mixer and presented to the BBB demodulator.

The input signal (subcarrier plus noise) is impressed on a 100-kHz IF in the first multiplier,[1] then multiplied by a square-wave subcarrier reference and simultaneously by a 90-deg shift of the reference. The 0- and 90-deg reference multiplied signals are band-pass-filtered at 100 kHz. The 0-deg channel is detected, low-pass-filtered, limited, and multiplied by the 90-deg channel. The resultant signal is a phase-error voltage which is filtered and controls the VCO. Such a system is recognized to be a form of a Costas phase-lock loop.

The BBB was built up using Computer Control Co. (3C) digital circuits and operational amplifiers. The choppers are basically operational amplifiers operating in the differential mode. The choppers were designed to operate over a range of 20 mV to 5 V (48 dB). This dynamic range allows operation down to $ST/N_0 = 0$ dB at 6 1/4 bit/s with a 20-mV signal in a 40-kHz bandwidth, accommodating $\pm 3\ \sigma$ noise peaks linearly. The band-pass filters are of the Q-multiplier type with a band width tunable between 200 and 1200 Hz.

As shown in Fig. 1, data demodulated from the subcarrier by the Costas loop is low-pass-filtered and digitized. The ADC enters data to the SDS 920 computer, in which bit synchronization operations are carried out. The bit synchronization algorithm used in the BBB follows "early" and "late" samples of data are squared, subtracted, and their difference is used to generate a timing error signal. The timing generator circuitry for the BBB was built from 3C logic.

A photograph of the baseband breadboard, the test instrumentation, and the computer console is shown as Fig. 2.

Baseband Breadboard Test Results

Initial runs on the BBB were made at a bit rate of 200 bit/s in order to allow debugging of the system with convenient signal levels and test times. Performance at this bit rate was found to be substantially in accordance with theory. Figure 3 is a plot of bit error rate versus ST/N_0, the ratio of energy per bit to noise spectral density. The experimental points are seen to be within 0.3 dB of theory; the experimental error is estimated as less than 0.2 dB at each individual point.

Also measured were the open-loop error curves for the subcarrier and bit-sync loops, Figs. 4 and 5, respectively. Figure 4 is seen to be a sawtooth wave as theoretically predicted; Fig. 5 is a sampled triangular wave as it should be.

Initial results at low bit rates are more pessimistic. For example, at 6 1/4 bit/s, using a 1-Hz loop bandwidth, it was found that the degradation due to jitter was on the order of 3 dB. Further investigation of low rate performance and tradeoffs is currently in progress.

The computer programs for the BBB were written to accomplish the required control and instrumentation functions for the equipment on hand. The software is organized as several subroutines, executed under interrupt control.

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[1] The word "multiplier" is used loosely here. In the mechanization, the multipliers are actually choppers.

For instrumentation purposes, several additional routines have been added to the main program to allow examination of the system at various points, somewhat increasing the required running time. Four additional routines are: (1) computation of the normalized signal to noise ratio averaged over 1000 data bits, (2) printout on the line printer of both the corrected and uncorrected data from the data integrator, (3) outputing of the bit timing error values to a digital-to-analog converter to generate the open-loop bit sync error curves for observation, and (4) writing the corrected value of data taken at bit sync time on magnetic tape.

Considerable effort has gone into the design and construction of test instrumentation for the BBB. The test setup has been designed so that it may be used with the prototype system with minimal changes. Some of the system parameters which are accurately measurable with the test setup are bit error rate, bit clock jitter, subcarrier jitter, bit acquisition time, and effective (internal) SNR.

MARINER 1971 CSAD

Goals

The near-term goal is to demonstrate a working breadboard FSK relay link at 500 bit/s by December 1967 suitable for use between an entry capsule and flyby spacecraft on a planetary mission. Two approaches will be considered for sync recovery: a separate transmitted bit sync tone and data-derived bit synchronization.

Progress

The data-derived bit synchronization is presently being investigated. An early-late gate type of bit synchronizer, breadboarded originally for Mariner Mars 1969 investigations has been modified to operate at 500 bit/s (see Fig. 6). Performance with white gaussian noise has been good - on the order of 0.2 dB degradation from hardline bit sync performance.

The synchronizer will be mated to an "audio frequency equivalent" of the proposed 30-mHz FSK receiver, shown in Fig. 7, to ascertain the performance when the input to the synchronizer is FSK demodulated data plus noise - which is colored and nongaussian. The breadboard receiver is nearly completed.

Because of the critical importance of low acquisition time in the Mariner 1971 mission, an automated acquisition tester has been built and tested. It automatically connects/disconnects signal to the channel, tests for in-lock condition of the synchronizer, and counts the time from first application of signal to receipt of in-lock indication. The data are automatically stored under computer control on magnetic tape for subsequent analysis.

Future Planned Activities

The completed breadboard system should be operational by the end of the reporting period. Acquisition and data performance will be tested for a variety of system parameters; among these are sync loop $2B_{LO}$, input frequency offset, S/N_O input, and PCM data codings, such as split-phase.

Work should also begin on evaluation of the pilot tone approach, with similar evaluations being anticipated.

Major Test Equipment Purchase

Procurement action for a programmable frequency synthesizer to be used as a precision, versatile FSK modulator is presently in process. Estimated value is $7,000.

Future Procurements

It is anticipated that procurement action will be initiated shortly to purchase/develop two analog functional elements, qualified for spacecraft use, that are used in the relay demodulator. They are the chopper and the limiter. Detail specifications have been written and are in the process of release.

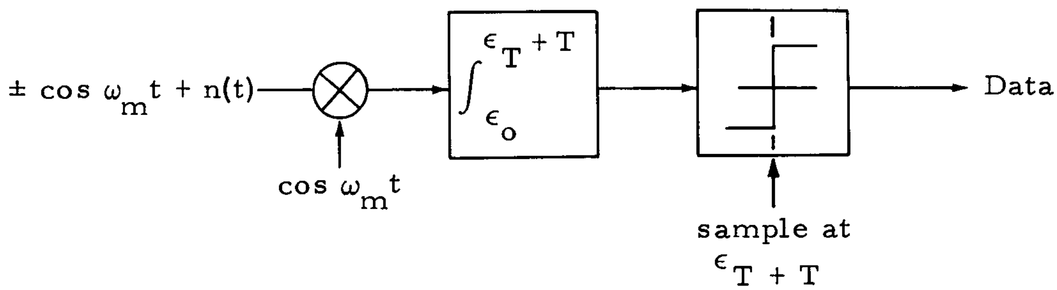
BIT SYNC JITTER STUDY

Goals

To perform an analytic and experimental study of the effects of bit-sync jitter on coherent PSK data detector performance. The case under consideration is where both the start and stop time are random variables, with correlation coefficient R(T). By choosing R(T) appropriately, the results are applicable to narrow or wide tracking loops, or to direct sync reconstruction schemes. The study will yield insight into how to design sync recovery systems to specified data performance requirements.

Progress

The coherent PSK detector with jittered bit sync timing has the form:



where $\frac{1}{T}$ is the bit rate, ω_m the subcarrier frequency, and ϵ_0, ϵ_T the samples of a random process T seconds apart. It is assumed that n(t) is white gaussian noise, ϵ_0 and ϵ_T are jointly gaussian with correlation R(T), signal and noise are independent, and that double frequency terms at the integrator input can be

neglected. For random data input, the average probability of error can be expressed as a sum of integrals of the form:

$$\iint_{\Omega} P(\epsilon_T, \epsilon_0) \operatorname{erf}\left[\sqrt{\frac{S\ (T \pm \epsilon_0 \pm \epsilon_T)^2}{N_0(T \pm \epsilon_0 \pm \epsilon_T)}}\right] d\epsilon_0 d\epsilon_T$$

where $P(\epsilon_T, \epsilon_0)$ is the joint gaussian density, the "±" indicate all possible combinations of signs, and Ω is the region where the integral is valid. In this model, the jitter is limited to $\pm T/2$. Jitter values outside this range correspond to a bit sync dropout for that period; prob $\{|\epsilon| > \frac{T}{2}\}$ will be added directly to the probability of error. Evaluation of integrals of this type is not available in closed form. Numerical integration is performed on a computer.

To perform experimental verification of the analytic results, a jittered bit sync generator was built. Samples of a low-pass filtered gaussian noise are the input to a voltage to pulse-width converter. The output is the jittered bit sync. The composite test setup is shown in Fig. 8. The low-pass filter rolloff point determines the correlation R(T) of the noise samples.

Activity on this study was suspended midway into this reporting period due to the higher priority of the Mariner 1971 effort. At that time, the experimental setup was calibrated and operating properly, but only the first few data points were taken. The computer program to evaluate the probability of error is about 50% completed.

Future Planned Activities

When time permits, the computer program will be completed and run, sufficient data will be taken to corroborate the analysis, and a TM will be written covering the results.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

JPL SPS Contributions

1. "Multiple Mission Telemetry Project," SPS 37-46, Vol. III (in process).

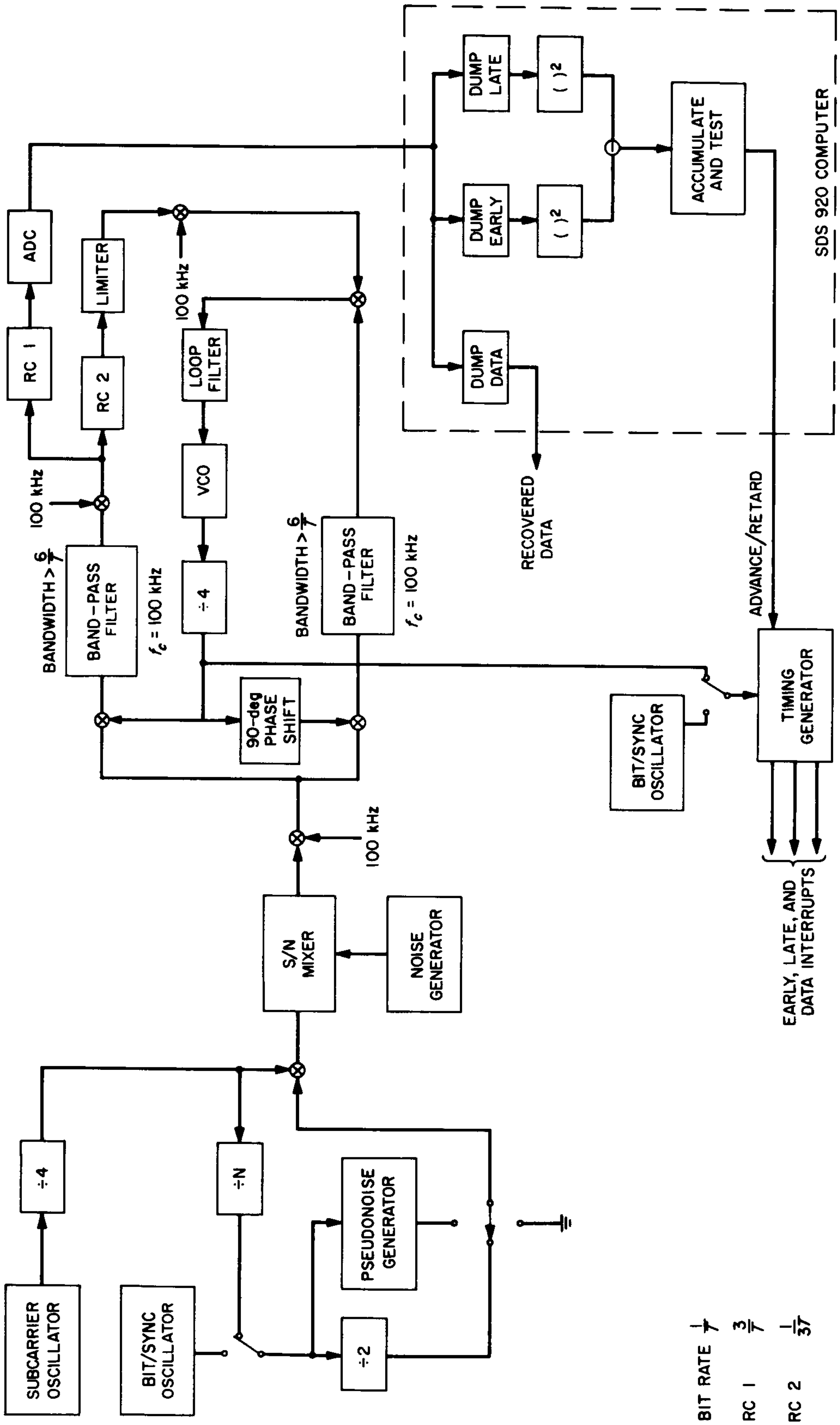


Fig. 1. BBB system diagram

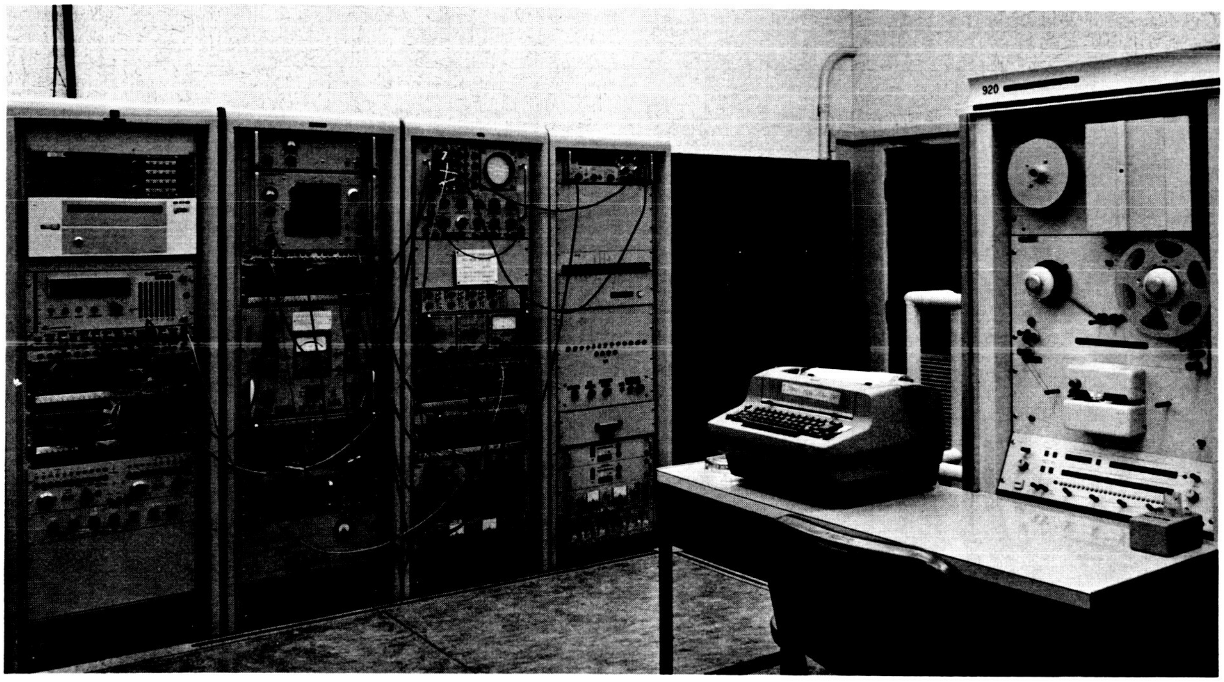


Fig. 2. Baseband breadboard, test instrumentation, and computer console

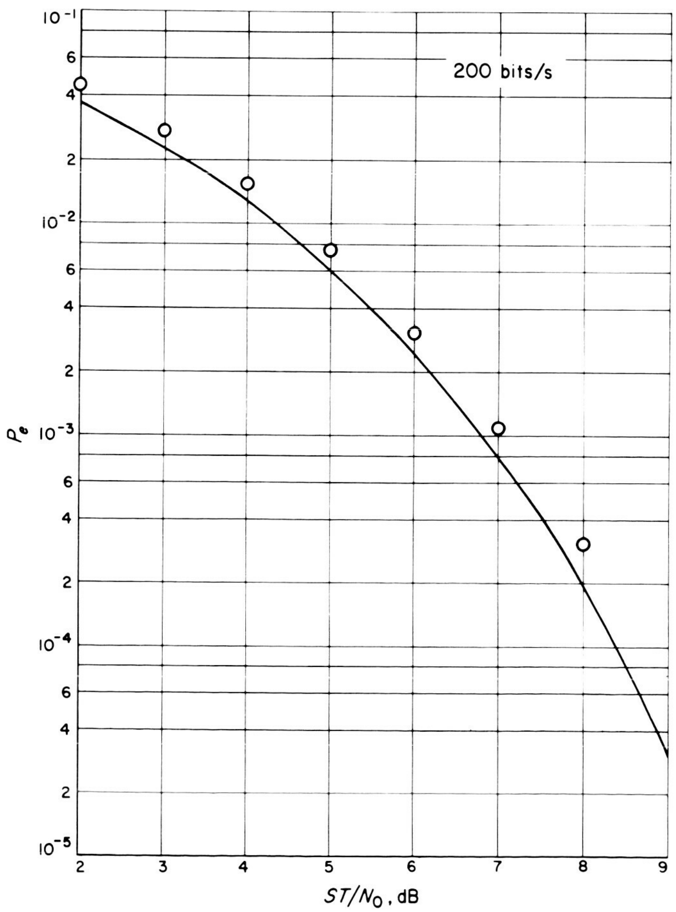


Fig. 3. Bit error rate vs ST/N_0

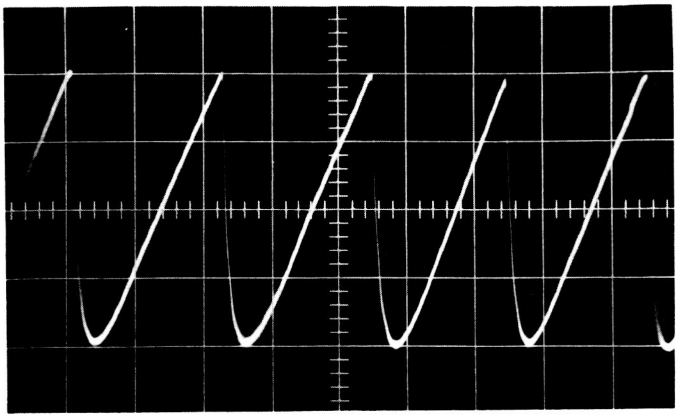


Fig. 4. Open-loop error curve for the subcarrier loop

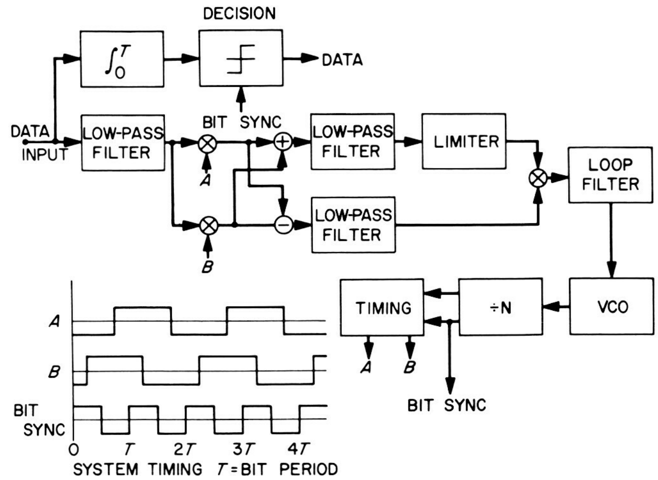


Fig. 6. Bit synchronizer

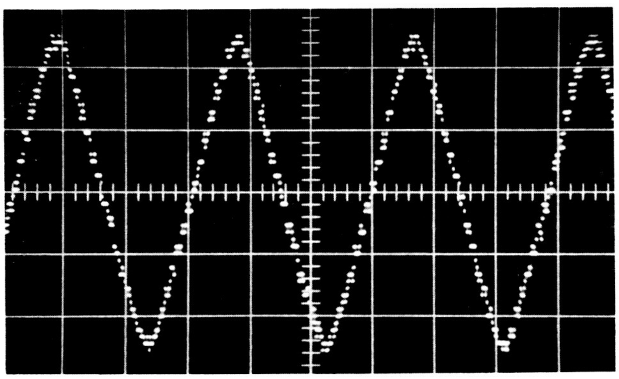


Fig. 5. Open-loop error curve for bit-sync loop

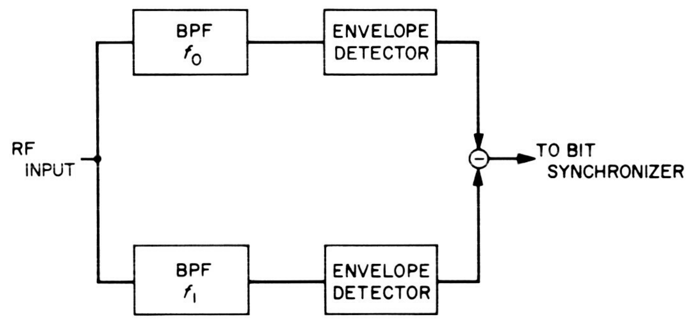


Fig. 7. FSK receiver

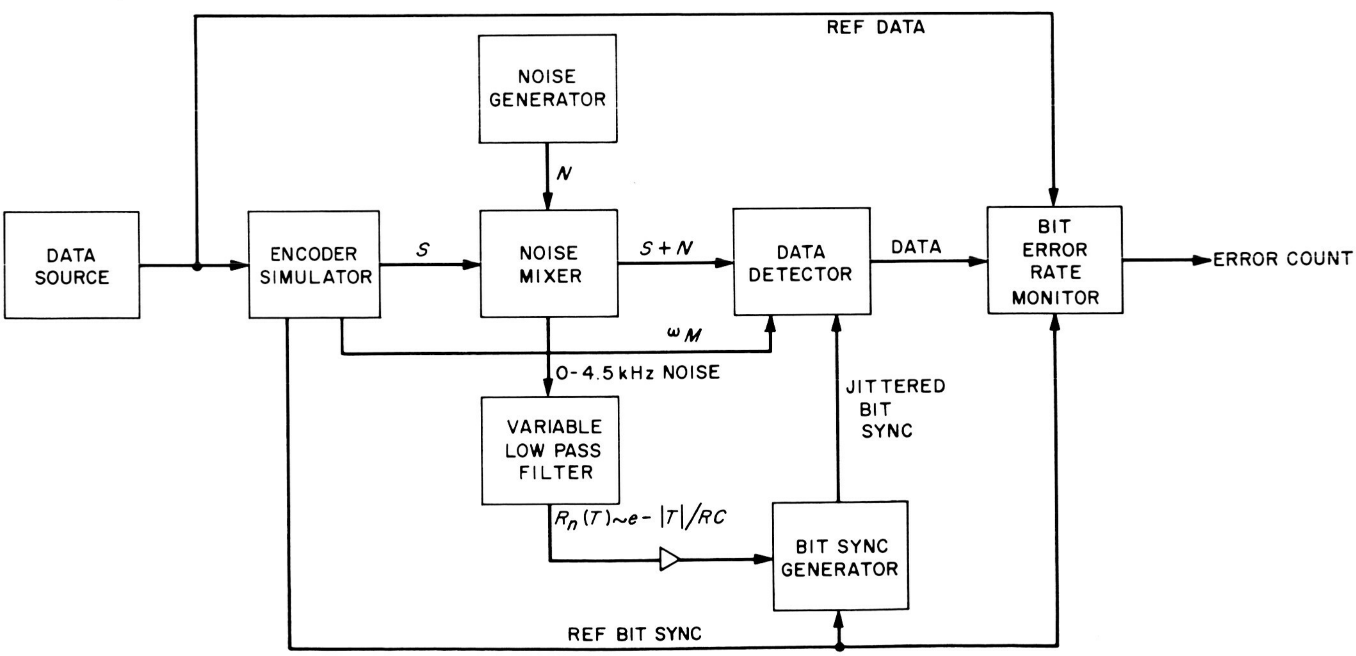


Fig. 8. Bit jitter study test configuration

RANGING TRANSPONDER
NASA Work Unit 186-68-04-20-55*
JPL 384-67901-2-3366

L. M. Hershey

OBJECTIVE

The objectives of this work unit are (1) to complete the development of the Mariner S-band, turnaround ranging transponder in order that the technique may be confidently employed by advanced projects and (2) to modify the Mariner transponder for multiple-project utility and to extend its ranging capability beyond lunar distances.

PROGRESS

The improvement of the Mariner C transponder design was originally defined as a two-phase task. The first phase consists of a study of the existing transponder circuitry, the recommending of design changes to the transponder, and the demonstration of the performance improvement capability of selected design changes by modifying an existing Mariner C transponder. The second phase was to be the fabrication of a complete engineering model transponder based on selected results of phase I.

Both phases were funded. The statement of work for phase I was written and approved, and procurement action was completed. Upon evaluation of the proposals, Philco-Ford SRS, was selected as the contractor and a contract for phase I only was signed on February 28, 1966 (JPL Contract 951290). The contract for phase II was not signed but funds were held for it, pending completion of phase I.

Because of the number of problems that were uncovered under phase I and because of the limitations of available resources, both manpower and funds, phase II was redefined. Funds that were being held for phase II were added to phase I by contract modification. Emphasis was placed on the measurement of ranging time delay variations with temperature.

Final results of the redefined testing program are expected early in the next reporting period.

Instead of developing a complete improved transponder in one step, development contracts will be let for improved modules, a few modules at a time. This improvement process will be continued until the entire transponder has been improved and upgraded. Module interface responsibility will be retained in-house.

TRANSPONDER DESCRIPTION

The S-band transponder provides the functions of a double superheterodyne command receiver, a phase-coherent transponder, a turnaround ranging transponder, and a telemetry transmitter. It employs three loops as shown on the block diagram

*Jointly funded under NASA Work Unit 150-22-17-03-55.

of Fig. 1. These loops are the ranging, automatic gain control (AGC), and automatic phase control (APC) loops. In the absence of a received signal from the DSIF, the spacecraft telemetry information is modulated on a signal whose frequency is controlled by an auxiliary oscillator. When a signal from the DSIF is present in the transponder receiver at a level of about -150 dB or higher, the APC loop will lock to it, and AGC voltage is developed in the AGC loop. This voltage, besides controlling the receiver gain for proper operation, also produces a command voltage that turns off the auxiliary oscillator and causes the 19.125-MHz VCO to be switched to the transmitter input in its place. In this manner, closing the APC loop provides an exact ratio of 240/221 between the transmitted and received frequencies. In addition the AGC voltage is telemetered to provide received signal strength information.

The signal received from the DSIF may have either ranging information or command information phase-modulated on it. The second mixer provides two outputs, one to the 9.56-MHz narrow-band command and APC channel and another to the broad-band 9.56-MHz ranging channel. The ranging code is demodulated by the phase detector in the ranging channel, amplified, and remodulated onto the transmitted signal along with the telemetry. The command information is demodulated by the phase detector in the narrow-band channel.

TRANSPONDER PROBLEMS

Because of the tight Mariner C schedule, some design problems had to be allowed to remain in the transponder. In order to correct them and to bring the transponder closer to the present state of the art, the transponder improvement program was begun.

The problems which remained in the transponder were system problems and problems peculiar to individual modules.

Three main system problems were found to exist. Solutions to two--the self-lock and AGC problems--were reported previously. The turnaround ranging delay problem is being studied now, and results obtained to date will be described.

Module performance parameters were unstable with temperature and voltage fluctuations, the modules were not readily reproducible; test and adjustment was a long and tedious process.

The ranging improvements are directed toward reducing the turnaround ranging time delay variations through the transponder and increasing the ranging modulation bandwidth.

The time delay through the Mariner C transponder varies with temperature by as much as 200 ns. The DSIF specifies a maximum variation of 100 ns, but future programs are expected to require a reduction of at least one order soon, and eventually two orders. A 3-h stability of 0.7 ms is required for calibration of charged particle effects on Voyager.

Delay measurements are being made with each module subjected individually to temperature tests in order to isolate the causes of the variations, and analysis of these effects is carried on simultaneously. Ranging modulation bandwidth improvements have been designed and tested. They are being applied on the Mariner Mars 1969 transponder, based upon results of this study.

Analysis and breadboard tests of partial and whole modules resulted in improvement of nine of the fourteen modules in the transponder. Ranging tests, now underway indicate need for further improvement of modules.

STUDY PROGRAM

Under the study program, as reported six months ago (TM 33-322 Vol. I, p. 260), seven modules were analyzed, three were breadboarded, and partial breadboards were built of four more. Since that report, the frequency divider was analyzed, and an improved video amplifier breadboard was built. This module is being tested at present. Additional analytical work was done on the Ranging System and on the mixer preamplifier, second IF amplifier, and isolation amplifier. Some of the results of this study are being incorporated in the Mariner Mars 1969 transponder and modules will be available for test from that program soon.

RANGING TESTS

The ranging test plan starts with overall tests of an old transponder. Ranging and S-band phase delay variations are taken with the transponder at 8 different temperatures and at 5 different input levels. Next, the same tests are repeated with each six-pack alone subjected to the temperature range; then each individual module is subjected to environment. Certain diagnostic checks are made to aid in the analysis of the results. Available new improved modules will be tested next individually, then in six-packs, and finally a complete transponder using all available new modules will be tested. The results of these tests to date will be described now.

First, the entire transponder was placed in a temperature chamber and ranging phase delay variations were measured at up-link signal levels of -70, -90 dBm, and -110 dBm over the temperature range of -10 to +75°C. The -90 dBm measurements were approximately the same as -70 dBm. Measured performance data at -70 and -110 dBm are shown in Fig. 2. Then similar measurements were made with each six-pack subjected to temperature variations by itself, while the remainder of the transponder was held at room temperature.

The 498-kHz phase delay variation of the entire transponder measured about 15 deg over the type approval temperature range.

However, when individual six-packs were subjected to temperature variations it was found that receiver package 1 (preselector, mixer-preamplifier, 47.8-MHz IF, 9.56-MHz IF, and X36 multiplier) produced a phase shift of 38 deg over the temperature range as shown in Fig. 3. Receiver package 2 (phase detector, frequency divider, VCO, isolation amplifier and video amplifier) produced a phase shift of 8.5 deg in the opposite direction shown in Fig. 4. The transmitter package (auxiliary oscillator and X30 multiplier) produced a phase shift of 11 deg shown in Fig. 5, also opposing the shift of receiver package 1. In order to further isolate and identify the causes of phase variations individual modules are being subjected to temperature variations as the next step.

To date, only the 9.56-MHz IF amplifier has been evaluated in this manner. Its effect on ranging delay, when it was placed in the temperature chamber alone, is shown in Fig. 6. The effect is much greater than that observed with its entire six-pack in the oven.

The 9.56-MHz amplifier is not directly contained in the turnaround ranging loop, it is a part of the APC loop that furnishes the reference signal for the ranging phase detector. It was therefore hypothesized that a change in the phase of the signal at the APC loop detector, caused by temperature variations, was affecting the ranging delay at the ranging phase detector by changing the phase of the reference signal.

To determine if this hypothesis was tenable, a measurement was made of the effect of ranging detector reference signal phase on the ranging delay through the transponder. A strong effect was found to exist.

To further test the validity of the hypothesis, the measured RF phase shift through the IF amplifier as a function of temperature and the measured effect of ranging detector reference phase upon ranging delay were used to calculate the effect of second IF temperature on ranging delay. The results were entered as points on Fig. 6. Fairly good agreement is demonstrated between -10 and +40°C, but the results deviate sharply at higher temperatures. The tentative conclusion was that the hypothesis is partially correct, but that some other mechanism was also contributing, and that the effect of the other mechanism was predominant at higher temperatures.

It should be noted that the 9.56-MHz IF amplifier used in these tests exhibits phase shifts in excess of the limits specified for this module, although it had been tested previously (and passed) to these specifications. The specified limit of ± 15-deg phase variation through the IF would result in 10-deg overall ranging delay variation, which is still a major contribution to the total.

The effect of the reference phase on ranging delay could not be explained by the analytical model commonly used for a phase detector, so some further investigation was undertaken.

The partial schematic diagram in Fig. 7 shows the principal ways in which the second IF amplifier module can affect the ranging signal. The command and ranging circuits are partially isolated from each other by the 18-Ω resistors in a Y configuration at the second mixer output. The input impedance to the second IF amplifier is 50 Ω resistive through a narrow frequency band of about 4.5 kHz centered on 9.56 MHz. The ranging signal occupies about 3 MHz bandwidth.

The reference voltage to the ranging phase detector is supplied from the VCO through the frequency divider, so its phase varies with phase variations from the second IF input to its limited output. Therefore, it appears that the ranging signal could be affected by a phase variation in the IF, VCO, or frequency divider. It could also be affected by the crystal filter's input impedance in a somewhat different manner. Here, impedance variations across the broad spectrum of the ranging signal causes phase and amplitude distortion of the ranging signal. The distorted signal is affected by phase variations in the ranging detector's reference voltage.

To investigate the crystal filter's effect, the amplitude and phase characteristics of the ranging channel from the second mixer to the isolation amplifier input range centered about 9.56 MHz using the normal circuit. The result seen in Fig. 8 showed over 6 dB amplitude and over 50 deg of phase variation over the frequency range.

The addition of 20 dB of isolation in the crystal filter input circuit reduced its effect upon the ranging signal to about 1 dB of amplitude and 10 deg of phase non-linearity in the ranging bandwidth.

In the Mariner Mars 1969 transponder, the addition is being considered of an isolation amplifier in the 47.8-MHz IF amplifier module to provide the necessary isolation.

An additional contribution to ranging phase delay variations was found in the frequency divider. When tuned in the usual manner, its output spectrum contained a substantial amount of VCO frequency divided by four and its odd multiples in addition to the desired VCO frequency divided by two. Careful tuning of the divider input circuit while observing the module's output on a spectrum analyzer resulted in virtual elimination of the undesired spectrum components, and a reduction of the effect of ranging delay on reference phase by about 1/3. The module specification is being changed to require the use of a spectrum analyzer for proper tuning.

The effect of reference phase error on overall ranging delay is shown in Fig. 9. When the frequency divider is properly tuned for a clean spectral output the slope of the curve is reduced by about one third. When, in addition, the crystal filter is isolated from the ranging channel, the effect of detector reference phase variations is reduced as shown in Fig. 9. The specified phase variation limit through the 9.56-MHz IF is ± 15 deg over the temperature range. This should produce less than ± 3 deg variation in the ranging signal, with the modified circuit.

VIDEO AMPLIFIER

The old video amplifier was analyzed and recommendations made for its improvement during the early part of the transponder study. Problems of particular concern to Mariner Mars 1969 were the variation in output level with temperature and time delay variations with input signal level.

A breadboard has been built of a new video amplifier using differential transistor limiters instead of the back-to-back diode limiters used in the old video amplifier. Tests of the new breadboard indicate superior performance in critical areas as shown in Table 1. The output level vs temperature performance has been improved by nearly four to one. The output variation with input level of the new module is too small to measure over ± 10 dB input range. The time delay of the new module varies about half as much as the old over the temperature range. Time delay over ± 10 dB input change is improved. The greater frequency response of the new amplifier resulted in a decrease in rise time from 80 to 55 ns, and improved filter characteristics reduced under and overshoots to negligible amounts. The new video amplifier will be used in Mariner Mars 1969.

OTHER MODULES

Some minor improvements have been made in the performance of certain other modules during this period. The mixer performance has been improved still more than the 1 dB worst case noise figure improvement reported last period. It was found that a selected low-noise version of the new hot-carrier diode used in the redesigned mixer can be substituted directly with a resultant transponder noise figure improvement of another 1/2 dB.

Table 1. Video amplifier performance

	Old	New
Δ Output vs temperature (-10, +75°C)	1.9 dB	0.5 dB
Δ Output vs input (±10 dB)	0.5	0.1 dB
Δ Delay vs temperature (-10, +75°C)	20 ns	10 ns
Δ Delay vs input (±10 dB)	20 ns	15 ns
Rise time	86 ns	55 ns
Overshoot/undershoot	5/10 %	0/0 %

The 9.56-MHz IF amplifier tuned circuits were temperature-compensated to reduce reference signal phase effects upon ranging time delay. This change was applied to the Mariner 1969 transponder.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Hershey, L. M., "Mariner S-Band Turnaround Ranging Transponder Improvement Program," SPS 37-43, Vol. IV.

2. Hershey, L. M., "Mariner S-Band Turnaround Ranging Transponder Improvement Program," SPS 37-44, Vol. IV.

Contractor Reports

1. Philco-Ford SRS Monthly Progress Reports for the months of January through June, 1967 (JPL Contract 951290).

ANTICIPATED PUBLICATIONS

JPL SPS Contributions

1. Hershey, L. M. "Mariner S-Band Turnaround Ranging Transponder Improvement Program."

Contractor Reports

1. Philco-Ford SRS Monthly Progress Reports.

2. Philco-Ford SRS Design Study of the JPL S-Band Turnaround Ranging Transponder-Final Engineering Report (JPL Contract 951290).

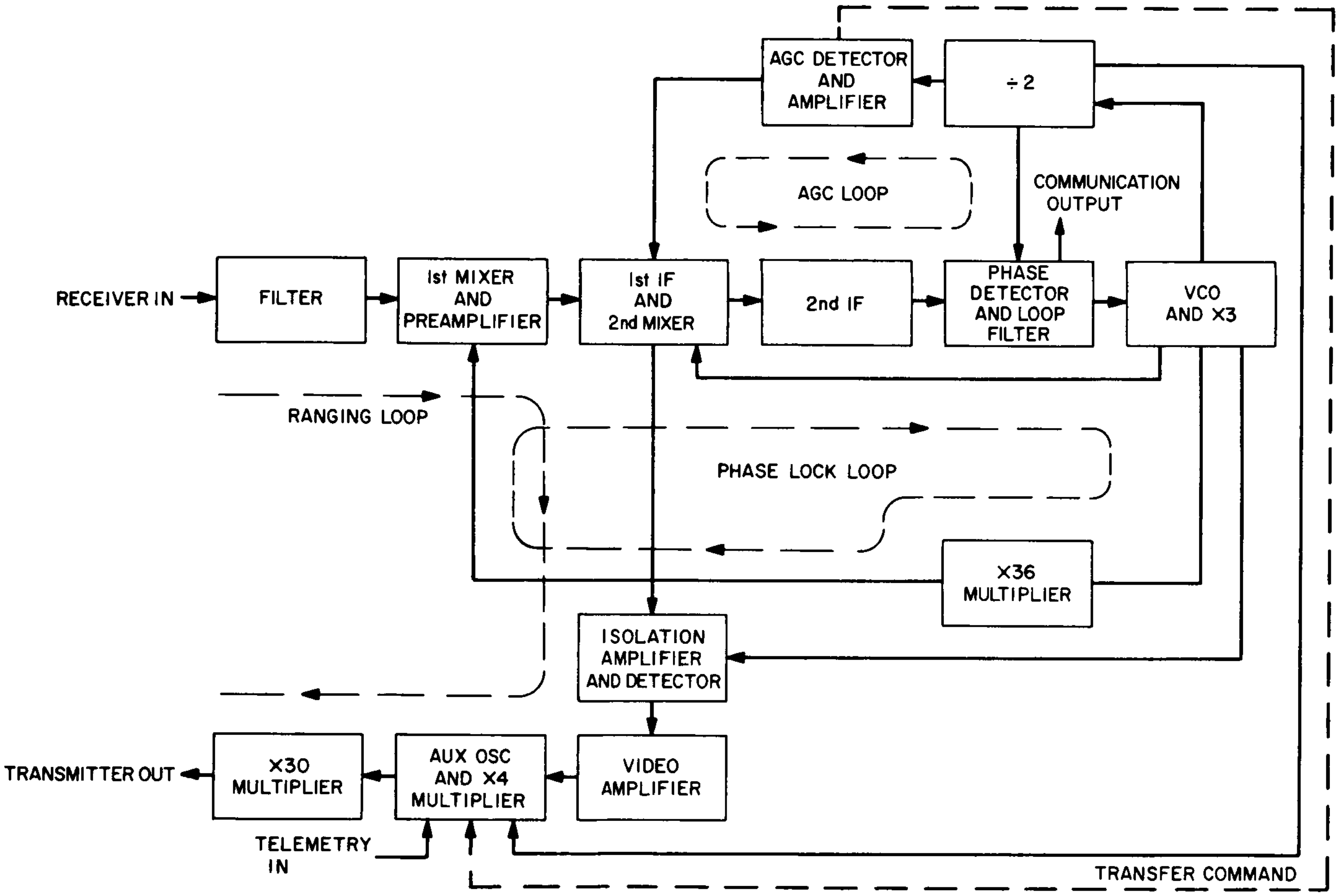


Fig. 1. S-band ranging transponder

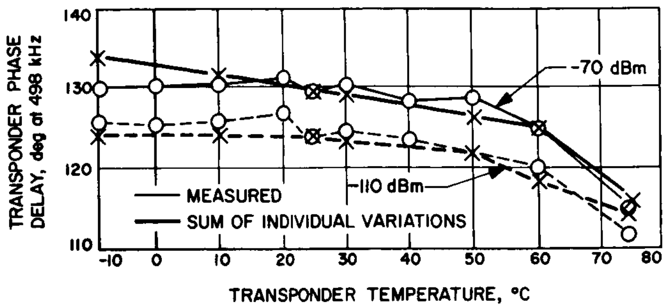


Fig. 2. Mariner C transponder ranging delay variations

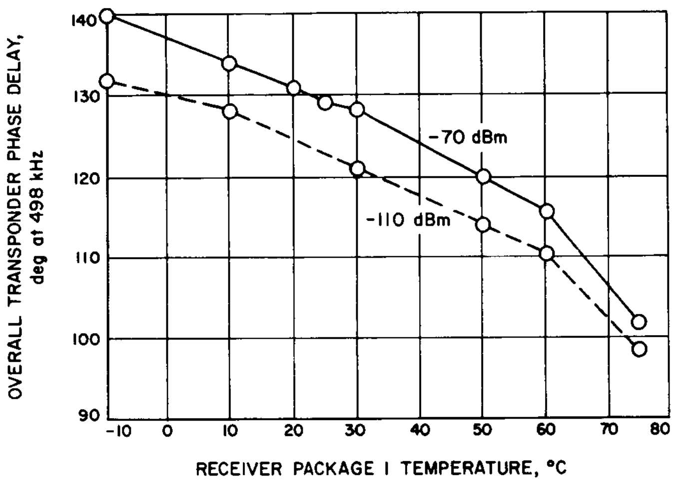


Fig. 3. Ranging delay variations vs receiver package 1 temperature

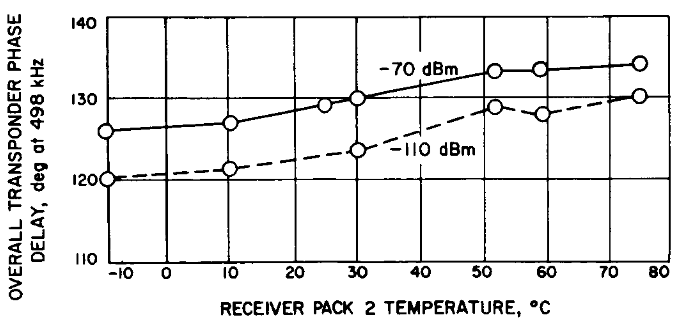


Fig. 4. Ranging delay variations vs receiver package 2 temperature

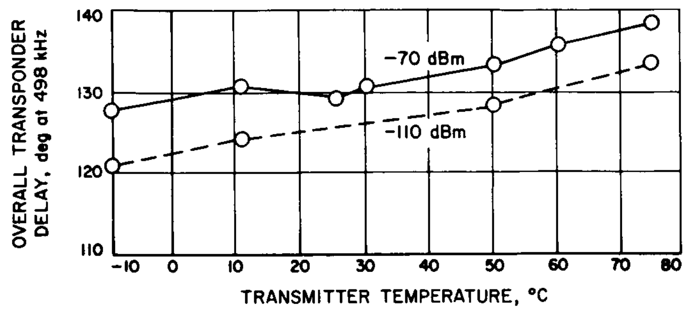


Fig. 5. Ranging delay variations vs transmitter peak temperature

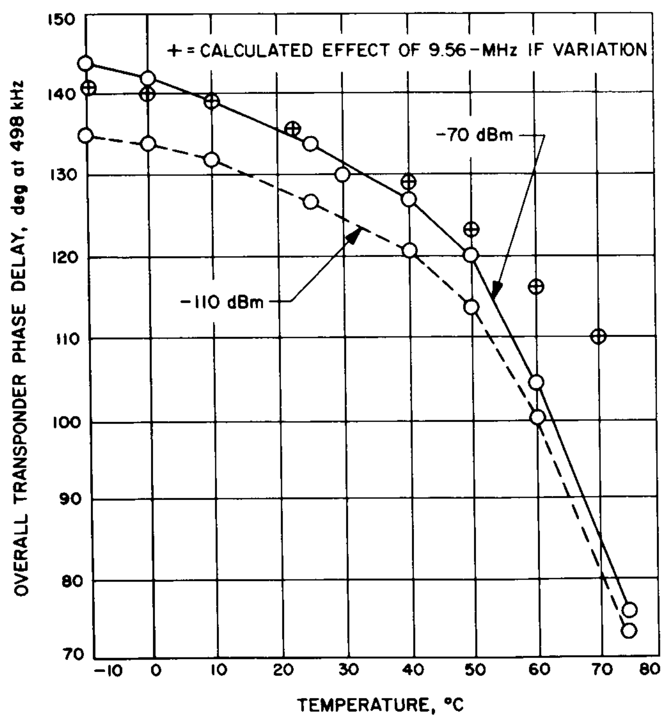


Fig. 6. Ranging delay variation, 9.56 MHz IF

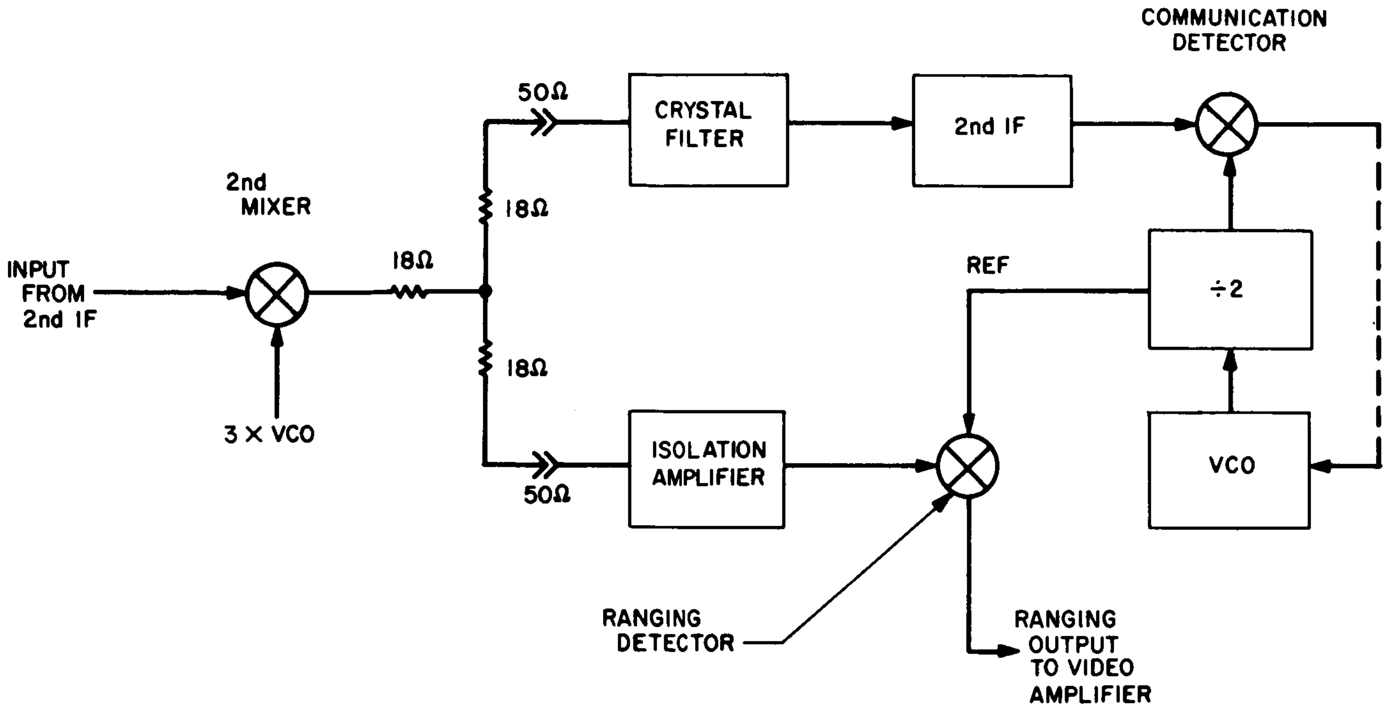


Fig. 7. Partial ranging diagram

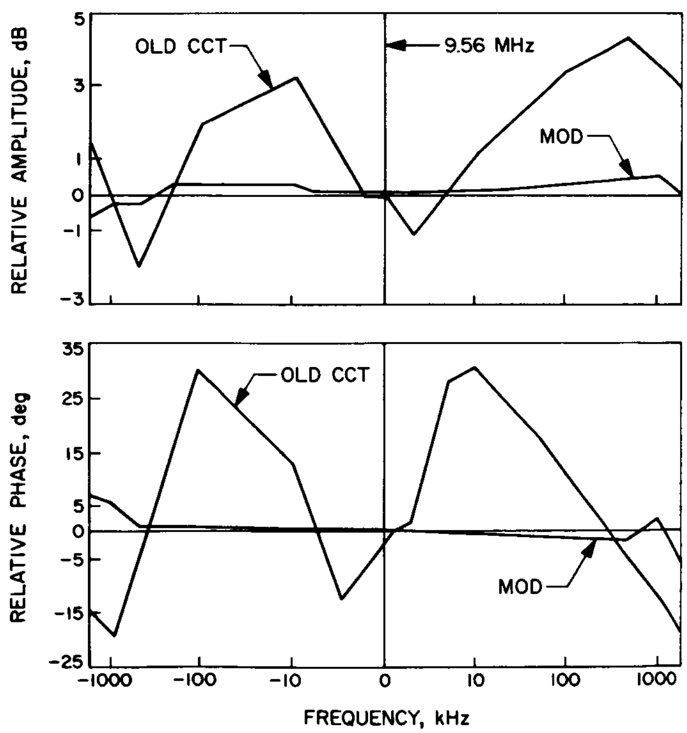


Fig. 8. Effect of crystal filter on ranging signal

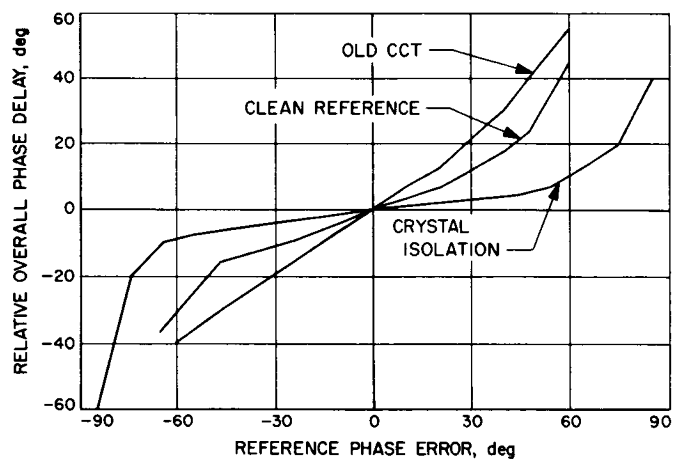


Fig. 9. Overall transponder ranging delay vs detector reference phase

PULSE HEIGHT ANALYZER DEVELOPMENT

NASA Work Unit 186-68-06-06-55
JPL 384-67101-X-3230

W. J. Schneider

OBJECTIVE

The objective of this unit is to develop an engineering model of a general purpose pulse height analyzer. This model will be of sufficient precision and versatility to be shared by a number of experimenters in support of their instruments aboard a spacecraft. In general, the results of this development will be used as a foundation from which to design future pulse height analyzers, whenever the need arises for such an instrument. Specifically, the pulse height analyzer is being designed to support the combination neutron experiment, which can provide remote chemical analysis of lunar and planetary surfaces.

PROGRESS

The electrical configuration of the ADC has been finalized. Some simplification was possible. The most significant is the elimination of the field effect transistors. Aside from greater confidence in freedom from possible oscillations, this eliminates the need for a 20-V power supply. The -100-V supply was changed to -50 V, thus reducing power consumption substantially.

All semiconductors are widely available, JEDEC-registered types. The circuit will usually meet specifications without any selection of components, but considerable improvement is possible with selection.

The final mechanical configuration of the ADC has also been designed. A breadboard version of the entire analyzer is nearing completion. The Ground Test Unit is done except for the wiring interconnecting the printed circuit boards.

PLANNED ACTIVITIES

The planned activities for the next report period include:

(1) Completion of the pulse height analyzer by the end of the first quarter of FY 1968.

(2) Beginning of tests and calibration of the pulse height analyzer with the JPL test unit will occur in the second quarter of FY 1968.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

Symposia Papers

1. Schneider, W. J., "Pulse Height Analyzer for Space Application," 2nd International Symposium on Nucleonics in Aerospace, sponsored by USAF, USAEC, and ISA.

TOUCHDOWN STABILITY STUDY
NASA Work Unit 186-68-09-03-55
JPL 384-63501-2-3500
J. A. Garba

OBJECTIVE

The objectives of this task are to conduct a three-dimensional stability study of a three-legged vehicle and to establish stability boundaries for the Surveyor spacecraft. Emphasis is place on the investigation of possible degradation of the stability boundary by the introduction of three-dimensional parameters.

APPROACH AND RESULTS

The Bendix Corporation, Bendix Products Aerospace Division, South Bend, Indiana, has successfully developed a computer program for the stability study of a three-legged vehicle landing on a hard surface. A stability investigation for the Surveyor spacecraft using the above program has shown that a slight degradation in the stability margin is to be expected due to the introduction of three-dimensional effects. However, the stability degradation is small enough to be of little practical consequence. This is particularly true for Surveyor, since here all stability boundaries were found to be far outside the range of landing velocities.

Computer predictions using the program have been compared with a full-scale Surveyor drop test. The results were published as a JPL TR.

For the simulation of a landing on a nonrigid surface, a modified version of the above program, accepting a simple analytical soil model has been developed by Bendix Products, Aerospace Division, and is available at JPL.

PLANNED ACTIVITIES

In a follow-on effort to JPL Contract 951304, it is planned to extend the computer simulation for a landing on a nonrigid surface. An analytical Surveyor footpad-soil interaction model will be developed by the Bendix Corporation, based on the experience obtained from analytical and experimental work presently performed for the LM vehicle by the contractor for NASA's MSC, Houston, Texas.

The extension of the contract, in the amount of $24, 000, is to be funded by the Surveyor project (NASA Work Unit 803-11-03-72-21). It has been negotiated and will be awarded in the near future.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Garba, J. A., "Touchdown Stability Study," SPS 37-41, Vol. IV, October 31, 1966.

JPL Technical Reports

1. Garba, J. A., A Comparison of Some Predicted and Measured Variables for a Full-Scale Surveyor Drop Test, TR 32-1084, March 1, 1967.

2. Sperling, F., and Garba, J., A Treatise on the Surveyor Lunar Landing Dynamics and an Evaluation of Pertinent Telemetry Data Returned by Surveyor I, TR 32-1035, July 15, 1967.

ANTICIPATED PUBLICATIONS

JPL Technical Memorandums

1. Garba, J., and Bookstein, D., Surveyor Lunar Touchdown Computer Program Usage Document. (Provisional title; being completed.)

ENGINEERING MECHANICS STUDIES
NASA Work Unit 186-68-09-04-55
JPL 384-62301-1-3500
J. E. Long

OBJECTIVE

The general objective of this work unit is to provide direction to the JPL Engineering Mechanics Division (35) advanced development program based on insight gained through JPL Future Project Studies.

EVALUATION OF INFLATED IMPACT ATTENUATORS—Isak Kloc

The broad scope of this effort is to investigate the applicability of an omnidirectional inflated impact attenuator concept to provide protection for a payload during terminal landing.

The feasibility of an inflated impact attenuator concept for landing on a smooth, flat surface has been demonstrated by test as reported in Ref. 1. The current scope is to investigate the inflated attenuator concept for landing on irregular inclined surfaces.

Evaluation

The potential problems of using an inflated attenuator for protection of payload during terminal landing on irregular inclined surfaces are:

(1) The payload will not reach a state of zero velocity during the initial impact. Consequently, the inflated attenuator requires multiple impact capability.

(2) Tangential forces and protrusion forces caused by surface irregularities tend to rupture the inflated attenuator.

A solution is to compartmentalize the attenuator to absorb impact energy by flow of the inflating gas through orifices in walls common to each compartment and to prevent a loss of the entire energy-absorbing system by a local rupture.

Two compartmentalized inflated attenuator concepts are considered. One concept places the axis of each pyramidal compartment radial to the payload, and the other places the hemispherical compartments on the exterior surface of an inflated spherical balloon. Information from LRC was obtained during the effort.

Future Activity

Preliminary design and analysis will be performed to obtain realistic weights since the joints and structural elements required to support the payload are significant contributors to the total weight. The efficiency of a compartmentalized attenuator will be compared with other attenuator systems including phenolic, metal, and balsa wood for various significant parameters.

EVALUATION OF SPACECRAFT PROTECTION DESIGN REQUIREMENTS FOR A JUPITER SPACECRAFT DUE TO ASTEROID AND METEOROID IMPACT—Moche Ziv

The scope of this evaluation is to refine the present estimates of design and performance requirements of asteroid belt protection for Jupiter spacecraft. The evaluation requires two major parts: (1) development of an interplanetary model for the meteoroid and asteroid environment and (2) evaluation of structural requirements to protect against the proposed environment. Effort will be concentrated on item (2). Previous effort at JPL has resulted in a micrometeoroid and asteroid model based on the existing data. These models will be accepted as inputs for this evaluation. As further refinements to the meteoroid and asteroid model are made (at JPL or elsewhere), they will be incorporated into the results of this effort.

Evaluation

Information obtained from the literature and personal discussions was used to determine the structural requirements for protection from meteoroids and asteroids for a Jupiter spacecraft.

Analytical refinements to improve the material penetration criteria for high velocities to 6 km/s were not made.

REFERENCE

1. Ross, R. G., and Layman, W., The Design and Testing of an Inflated Sphere Impact Limiter, TR 32-1037, December 15, 1966.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

SPACECRAFT DESIGN TECHNOLOGY

NASA Work Unit 186-68-09-06-55
JPL 384-63801-2-2920
J. Gerpheide
F. E. Rosell, Jr.

OBJECTIVE

The objectives of this task are (1) to develop insight into the alternative design and technology approaches for future spacecraft missions and (2) to prepare data which will serve as background information during subsequent project design and mission study periods.

STUDY APPROACH

The approach in this study is directed toward extending the functional analysis technique now in use in system study and system design efforts at JPL. By means of this technique, the objectives of a mission are converted into the functional performance requirements that must be met by the system. Various combinations of the possible subsystem mechanizations capable of performing these functions are formulated, yielding a number of systems potentially capable of carrying out the mission objectives and illustrating a variety of overall system philosophies. These combinations are then examined for performance level, system integration problems, probability of mission success, state of the art, and relevant parameters.

TASK SUMMARY

This task covers three subtasks:

(1) Spacecraft Design Data Information System.

(2) Spacecraft Data Management and Control.

(3) Asteroid Belt Hazard Model.

Drastic curtailment of funds in January 1967 resulted in realignment of this project from Spacecraft Design Technology to Advanced Systems Technology, NASA Work Unit 186-68-09-09-55, JPL 384-706XX-2-2920.

Activity during this reporting period was confined to closing out the SDT subtasks and realigning the task efforts. ORAD FY 1967 FOP Change 74 of March 30, 1967, established a ceiling of $57,000 for this task effort for this report period.

SPACECRAFT DESIGN DATA INFORMATION SYSTEM

The objective of this task is to design, develop, and implement a technical information system for space flight project data that could be used as a base for the development of advanced technology. The information system would include spacecraft design information for all flight-proven space hardware and project data.

Essential usage objectives envisioned for this system were covered in detail in the previous semiannual report.

NASA decommitment of funds in January 1967 ($150,000) precluded a phase II contract and resulted in termination of this subtask. Except for collecting and filing information already developed, no work was accomplished during this reporting period. Further work on this subtask is not anticipated.

SPACECRAFT DATA MANAGEMENT AND CONTROL

The objective of this study is the evaluation and application of new technology for the management and control of spacecraft and mission data. The purpose of the study is to develop a rationale for the selection of a proper technical approach for handling new requirements of future projects.

Because of a change in technical emphasis from NASA and nonavailability of funds, this subtask was terminated at the beginning of this report period. No further effort is anticipated on this subtask.

ASTEROID BELT HAZARD MODEL

The objective of this in-house study is to develop analytic approaches to evaluate the probabilities of success of a spacecraft system penetrating and traversing the asteroid belt in future outer planet missions and, also, to develop such models to construct computer programs that would be useful in the parametric study of optimal technical approaches.

Accomplishments During Reporting Period

Draft of the study report was completed except for Appendix VII, "Computer Program."

Study Results

Trajectories through the asteroid belt in the ecliptic plane require more shielding mass for protection against meteoroids, whereas trajectories out of the ecliptic plane require more propulsion mass. This report describes a method for minimizing the sum of the shielding mass and propulsion mass for a given probability of no meteoroid penetrations of the spacecraft shield.

Based upon 1500 numbered asteroids, a model of the asteroid belt is developed. The meteoroid particle flux is represented by the equation

$$\Phi = \alpha_c m^{-\beta}$$

where Φ = particles meter^{-2}sec^{-1} of mass m or greater,

$$\alpha_c = \text{constant}$$

$$\beta = \text{constant}$$

A mathematical model is given for P(s), the probability of successfully traversing the asteroid belt, or P(0), the probability of zero penetrations of the spacecraft shield. The spacecraft is represented by a 26-sided convex polyhedron. The spacecraft trajectory is assumed to be in the form of an elliptical orbit. The meteoroid capability of penetrating the spacecraft shield is included as a function of meteoroid size, density, and relative velocity, and shield thickness, density, and hardness. The probability, P(0), is calculated as a function of spacecraft size, surface area, shield thickness, and shield mass.

Two cases are considered: (1) uniform shielding over the entire surface of the spacecraft and (2) optimum shielding so as to maximize P(0) for a given spacecraft shape, size, and shielding mass. Calculations are made for 500- and 900-day mission spacecraft orbits, for $3\beta = 1.9$ and $3\beta = 3.0$. In the judgement of the authors the best estimate for β is $3\beta = 1.9$.

It is planned to include in the report the computer program, which will permit a designer to vary the spacecraft parameters related to mission trajectory, the asteroid belt model, the spacecraft shape, size, and shielding material. This will enable the designer to maximize P(0) and to minimize the sum of the shielding mass and propulsion mass.

Future Plans

Preparation of the computer program in a form suitable for inclusion in the report, and publication of the study report are anticipated during the next calendar quarter.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

1. Neustadt, M., and Alderson, D. J., "Asteroid Belt Meteoroid Hazard Study."

ADVANCED SYSTEMS TECHNOLOGY

NASA Work Unit 186-68-09-09-55
JPL 384-70601-2-2920

J. Gerpheide
E. Kane Casani

Historically, advanced development at JPL has been conducted at the subsystem level with the intent of putting the subsystem organization in the best position to undertake a project at the appropriate time. This approach tends to move most disciplines on a broad front, sometimes unnecessarily and sometimes leaving a key area unattended. As a means of protecting against these pitfalls, focusing the JPL Advanced Development Program, and gaining some insight into the system level problems, a new advanced development concept has been initiated in March of 1967: system level advanced development.

The first task was to pursue the system design of a planetary entry capsule. The Mars 1971 opportunity was used to give some real constraints to the design of the system for the generation of a mission. This work is being carried out at the present time under the Capsule System Advance Development (CSAD) Program.

The objectives of this program are:

(1) To provide a means for getting experience in several critical and new technologies related to planetary capsule missions.

(2) To develop an understanding of the subsystems such that realistic performance estimates can be made.

(3) To obtain an improved understanding of planetary entry capsule system design and integration problems.

The program approach is as follows:

(1) Design, integrate, develop, and fabricate an entry system that will ultimately have at least the following subsystems:

   (a) Aeroshell.

   (b) Relay communication.

   (c) Power.

   (d) Mass spectrometer.

   This entry system will be subjected to a series of functional tests, to the sterilization heat cycle, and to selected environmental tests.

(2) Design, integrate, develop, and fabricate a small lander package capable of being integrated into the entry system and ultimately have at least the following subsystems:

   (a) Impact limiter.

   (b) Direct radio.

   (c) Power.

   (d) Sequencer and timer.

   (e) Orientation scheme.

   (f) Simulated parachute and mortar.

   This lander package will be subjected to functional tests, to the sterilization heat cycle, and to impact tests.

In the course of this work, a feasibility model (FM) is being constructed. This feasibility model will be a functioning engineering model patterned after the capsule system described in JPL EPD-427, Mars '71 Technical Study. The mission described in that document will be considered representative of planetary capsule missions and used, as required, to generate a set of representative mission requirements needed to conduct a meaningful system design. It is not intended that this model be a complete working capsule system, but that it demonstrate specific subsystem capabilities that are unique to a planetary capsule mission and not as well understood as interplanetary spacecraft design.

The purposes of the FM are:

(1) To demonstrate required key subsystem technologies in a functional capsule system.

(2) To expose a functional capsule system to the terminal sterilization environment.

(3) To gain experience in the system test and operations of a planetary capsule.

The FM will vary in capability from element to element in that some subsystems will be nonfunctional mockups, while others will be flight-designed although not flight-qualified. A general description of the hardware required is shown in Table 1. A more detailed hardware requirements description of each element of the capsule will be documented in the Capsule System Advanced Development Functional Description. Since it is not practical, with the resources available, to design, fabricate, and test a complete engineering prototype capsule system, only those elements that contribute directly to accomplishing the stated program objectives will be incorporated in the FM.

Figure 1 is the schedule to which the program is set. The program guidelines have been issued in EPD 491, "Capsule System Advanced Development Program Guidelines," April 25, 1967.

The Capsule System Advance Development has made significant progress since its inception:

(1) The capsule system design is well into its final stages.

(2) The system functional block diagram has undergone several iterations and is now settling down to reflect a sound system design.

(3) A first level system logic diagram has just been started and will be developed in the near future. This diagram is extremely useful in identifying weak points in the design and complementary to the system functional block diagram.

(4) The data handling subsystem functional design has been completed. This design satisfies a representative set of science and engineering requirements within the constraints of weight, power, volume, and relay communications system capability.

(5) A full-scale mockup of the capsule system has been built (see Fig. 2). The mockup has been useful in identifying the class of assembly and operational problems to be encountered with this class of capsule.

(6) Development testing on the new nonspherical lander impact limiter has demonstrated the feasibility of such a lander shape. The lander has an impact limiter which is a low aspect (5:1) cylinder (see Fig. 3).

(7) A landing digital simulator program using Monte Carlo techniques has been developed. This program calculates the probability of landing success for a lander designed to a specific set of design conditions. This is done by statistically defining the landing conditions from probability density functions of the surface atmosphere temperatures, the surface pressure, the atmosphere molecular weight, the winds, the slopes, the curvature, and the bearing strength. Analytical results of this program have been compared with actual hardware test results and indicate adequate margin in the lander design.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

Table 1. Feasibility model subsystem hardware requirements

Subsystem	Type*
Entry Structure (Internal)	II
Relay Radio Subsystem	I
Entry Power Subsystem	II
Entry Sequencer and Timer	IV
Entry Data Handling Subsystem	IV
Pyrotechnic Subsystem	I
Entry Cabling	II
Propulsion Subsystem	III
Entry Temperature Control Subsystem	II
Entry Mechanical Devices Subsystem	III
Parachute Subsystem	III
Aeroshell	I
Entry Data Storage	IV
Sterilization Canister	II
Spin-Despin Subsystem	III
Entry Accelerometer Package	III
Entry Pressure Probe	III
Entry Temperature Sensor	III
Mass Spectrometer	IV
Radiometer	III
Lander Structure	I
Direct Radio Subsystem	I
Lander Power Subsystem	I
Lander Sequencer and Timer	IV
Lander Data Handling Subsystem	IV
Lander Cabling	II
Lander Temperature Control Subsystem	II
Lander Mechanical Devices Subsystem	I
Lander Data Storage Subsystem	IV
Impact Limiter	I
Lander Science	III

*All subsystems are classed as follows:

Type I - A functional engineering model.
Type II - A functional element which will satisfy specific interface requirements of other subsystems.
Type III - A mechanical configuration mockup.
Type IV - To be determined at a later date.

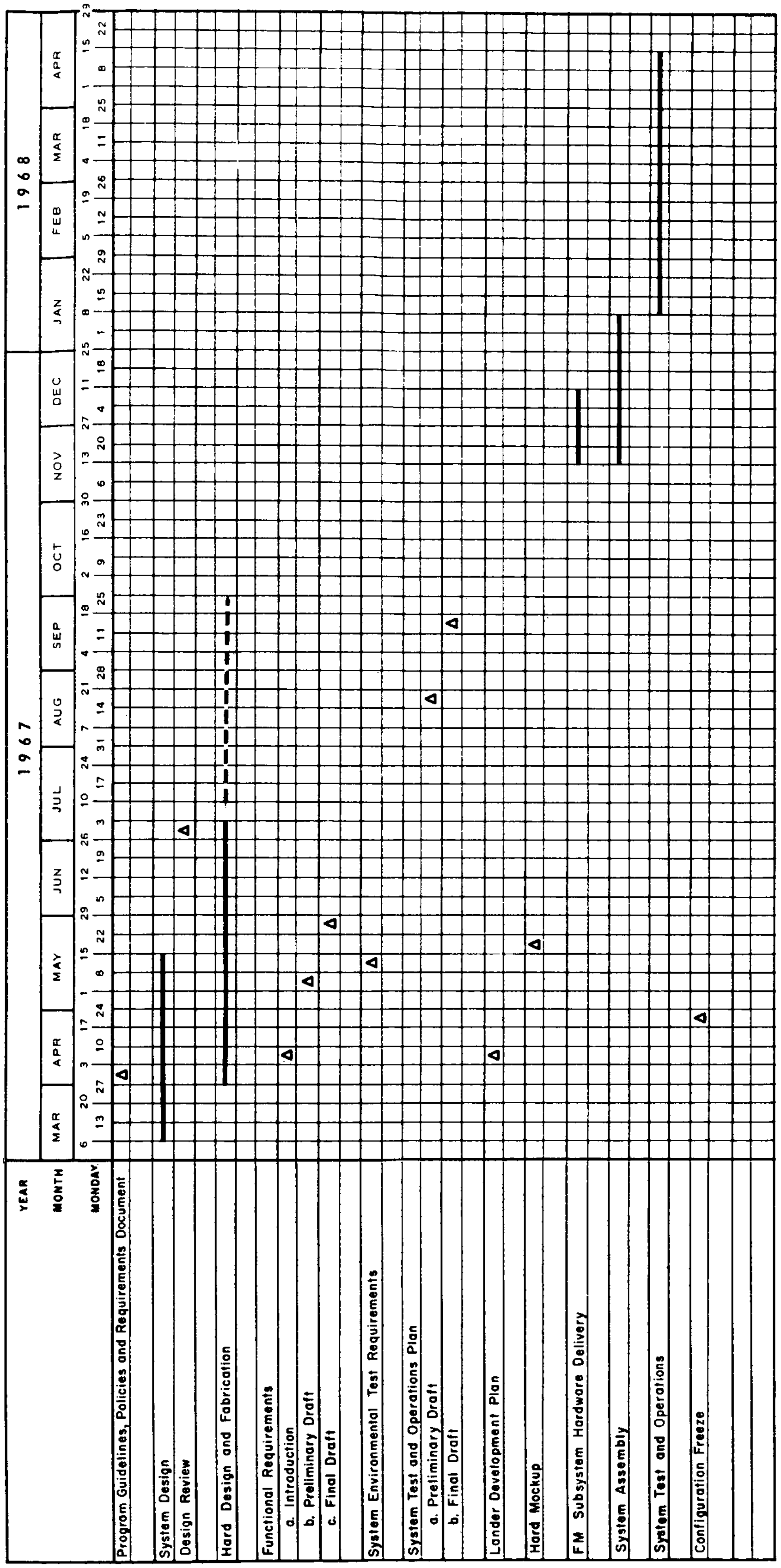


Fig. 1. Capsule system advanced development schedule

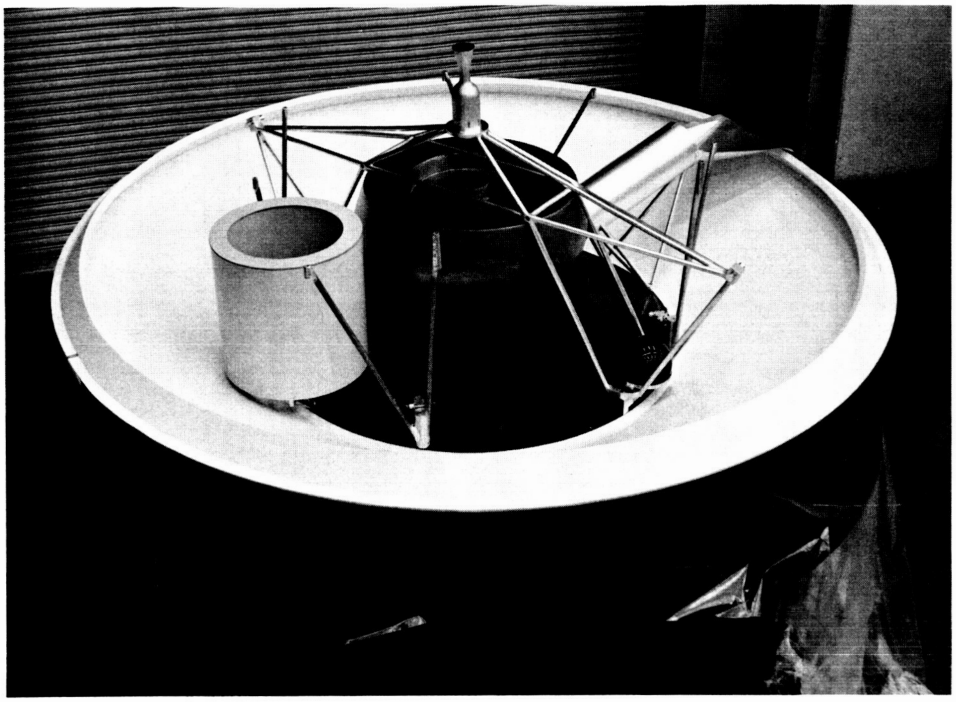


Fig. 2. Capsule system mockup

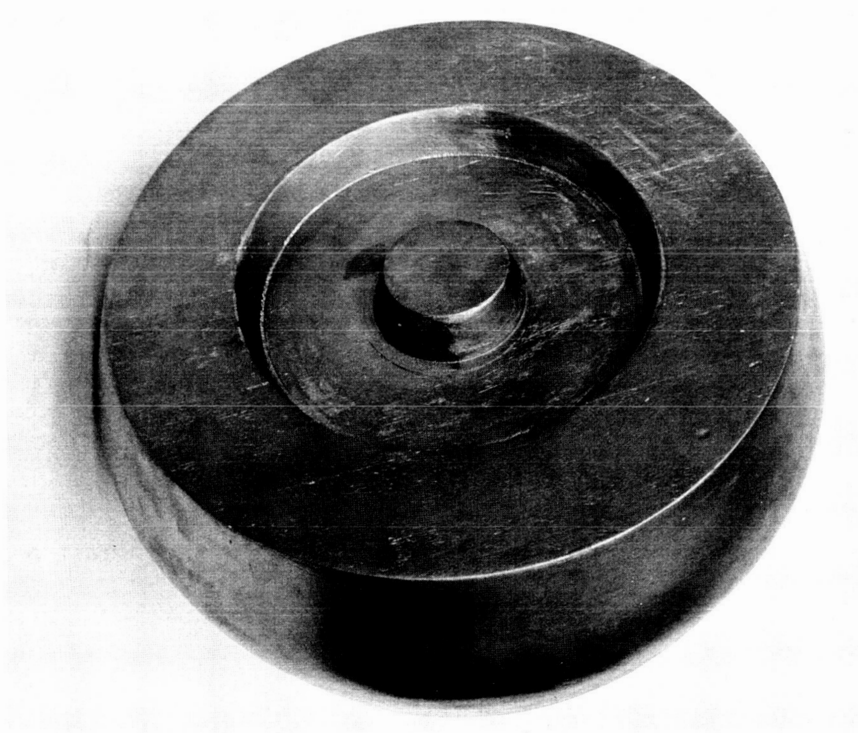


Fig. 3. Nonspherical lander impact limiter

MECHANICAL RESPONSE TO HIGH IMPACT

NASA Work Unit 186-68-10-03-55
JPL 384-65601-2-3550

J. O. Lonborg

OBJECTIVE

To intelligently plan an unmanned landing mission requires knowledge of the impact survival levels for which spacecraft equipment can be designed and of the increased weight and other costs associated with higher impact survival capabilities. During past years high-impact survival efforts have yielded information concerning the impact survival capability of many electronic and mechanical components and have resulted in a better understanding of necessary design techniques for ruggedizing mechanisms and mechanical parts. This work unit continues the investigation of the response of mechanical devices and components to high impact, with the objectives of refining equipment and fixture design techniques and of providing impact survival information concerning mechanical devices larger and more complex than those previously investigated.

PROGRESS

During the second half of FY 1967 this work unit has been reshaped, within the constraints of the objectives and available resources, to provide support to the Capsule System Advanced Development (CSAD) program.

The experimental ruggedized tape transport mechanism mentioned in the previous semiannual report is nearly complete. Preliminary operating tests have disclosed the need for some modifications of the mechanism. Because of priorities, completion of the construction and testing of this machine has been delayed and is now scheduled for the first half of FY 1968.

A significant amount of work has been done in cooperation with other JPL technical divisions in the development of specific items of ruggedized equipment. This has included consulting on high-impact design problems, design of test fixtures, and participation in the performance and evaluation of high-impact tests. This activity is beneficial both to the specific equipment development programs involved and to this work unit, those equipments serving as vehicles for mechanical response investigations. Tasks with which this work unit has been thus involved during this reporting period include: the high-impact traveling wave tube amplifier (Fig. 1), high-impact antennas (JPL Division 33), and sterilizable high-impact batteries (JPL Division 34). The traveling wave tube program was a particularly interesting one in that the geometry that is dictated by functional requirements is particularly unfortunate from the standpoint of impact survival. The tube is substantially a long bar, whereas it is generally preferable that the specimen have comparable dimensions in all principal directions.

Based on the study of capsule erection schemes performed under "Advanced Mechanisms" (NASA Work Unit 186-68-12-05-55), the CSAD project tentatively adopted the self-orienting "heads-or-tails" configuration conceived therein. Design, fabrication, and drop-testing of the first model (Fig. 2) were accomplished

in this work unit. The model consisted of a 16-in.-diam by 5-in.-thick hardwood simulated payload surrounded by a balsa wood impact limiter 2 to 3 in. thick; the whole weighing approximately 45 lb and resembling a wheel and tire. Preliminary calculations indicated that if the capsule impacted an unyielding surface at a maximum velocity of 125 ft/s, the maximum resulting shock acceleration would range from about 1200 g (for impact on the edge of the limiter) to 2500 g (for impact against the flat side of the limiter).

Lacking any other suitable means for obtaining shock data from helicopter drop tests, a three-axis, three-level acceleration indicating device (Fig. 3) was developed based on earlier high-impact investigations (see JPL SPS 37-15, Vol. IV, pp. 107-108). Each bidirectional sensor consists of a single proof mass in contact with a Styrofoam pellet on either side. Postimpact examination of each Styrofoam pellet (for crushing or lack thereof) establishes whether or not the component of acceleration in that direction exceeded the critical level established by the crushing strength of the pellet and the magnitude of the proof mass. The device was calibrated both statically and dynamically (at 50 ft/s impact velocity).

The first model of the CSAD capsule was dropped a total of 11 times from a helicopter onto targets of asphalt paving, asphalt paving covered by 6 in. of sand, a dry lake bed, and a boulder field. Impact velocities were of the order of 125 ft/s. Maximum indicated shocks did not exceed 2500 g; this has since been confirmed by more elaborate impact limiter development tests performed under a different work unit.

It is planned that this work unit will participate in the performance of more sophisticated impact tests on future models of the CSAD capsule, and additionally, in the development of specific equipments for the capsule, such as batteries, power conversion equipment, communications equipment, and sequencers.

PUBLICATIONS DURING REPORT PERIOD

Papers Presented at Meetings or Symposia

1. Lonborg, J. O., "Current Status of Design Accomplishments for Shock Levels of 10,000 g," ASME Design Engineering Conference, New York City, May 16, 1967.

2. Johnson, N. E., "An Analytical and Empirical Approach to Design Components," ASME Design Engineering Conference, New York City, May 16, 1967.

ANTICIPATED PUBLICATIONS

None.

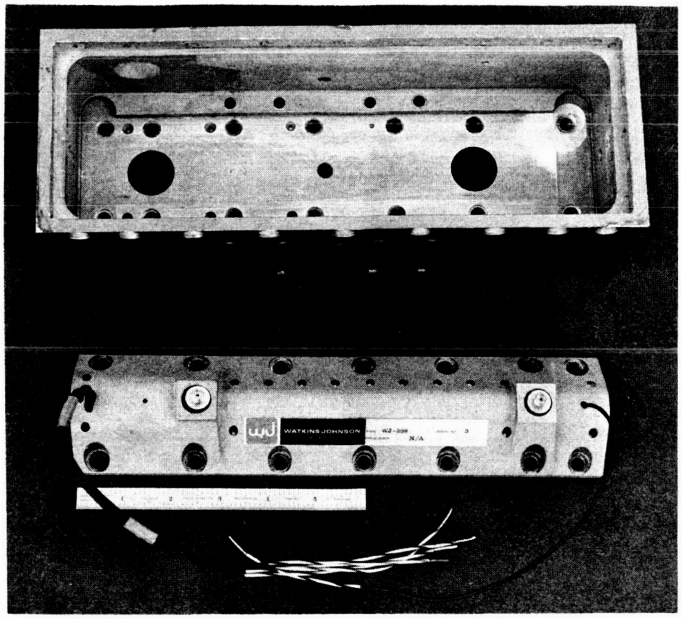


Fig. 1. High-impact traveling wave amplifier

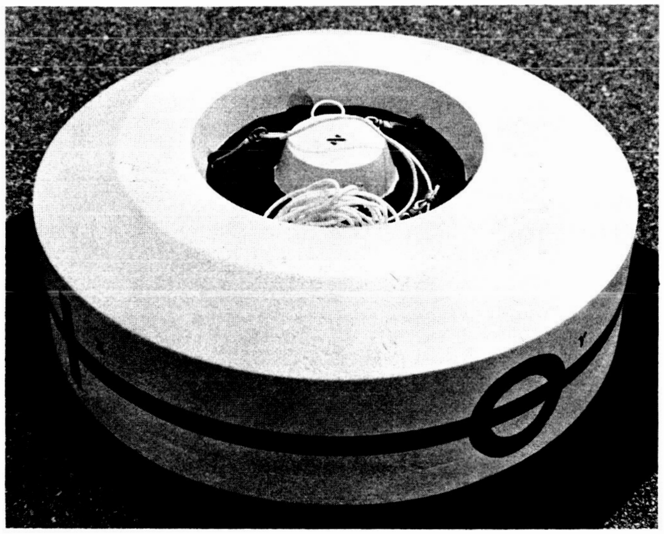


Fig. 2. CSAD capsule model

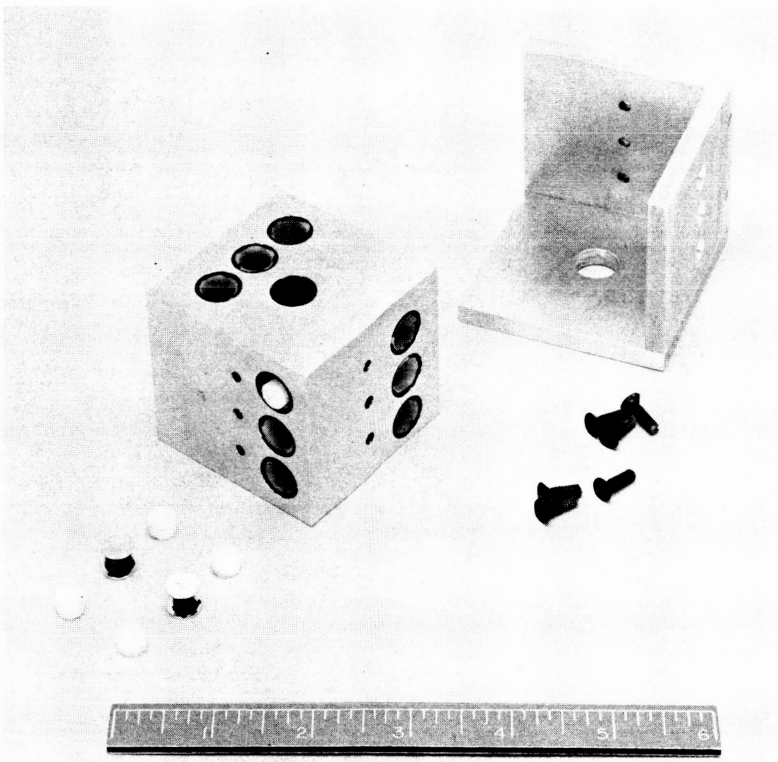


Fig. 3. Three-axis, three-level acceleration-indicating device

HIGH-IMPACT TEST EQUIPMENT DEVELOPMENT

NASA Work Unit 186-68-10-04-55
JPL 384-65701-2-3550

J. O. Lonborg

OBJECTIVE

The objectives of this work unit are to continue to upgrade existing high-impact test equipment and to develop new equipment and techniques, as required, to support experimental high-impact investigations being performed by the Engineering Mechanics and other JPL technical divisions. This work unit is the key to the success of the JPL high-impact program, since it provides testing capability to an effort which is extremely experimental in nature. Equipment must be available in case the Laboratory should, on short notice, undertake a flight program requiring high-impact technology.

PROGRESS

Centralization and upgrading of the high-impact test facility has continued during this period. The 22-in. air gun facility has been roofed for weather protection, and an outside door has been cut through for better access. The new sling shot (Fig. 1), incorporating improved cocking and release mechanisms, has been installed in the centralized facility and is now in operation. The old sling shot has been transferred to JPL Division 37 for use in performing routine high-impact tests, thus freeing the new machine for further test equipment development work and for performing special high-impact tests. Provision has been made for installing a 6-in. air gun, but actual installation has been postponed pending possible availability of the improved gun developed for the JPL Space Technology Applications program. The 50-ft drop-test facility is being relocated in proximity to this installation. Instrumentation and operating controls for the high-impact testers have been consolidated in a van adjacent to the centralized facility and permanent connecting lines are now being installed.

Due to conflicts with other facility improvement work, only one additional development firing of the 22-in. air gun has been made since the last report. As indicated in that report, the immediate objective is the production of a 10,000-g, 1-ms shock pulse for testing of JPL Division 33's traveling wave tube amplifier. The results of this test indicate satisfactory progress toward satisfying all objectives except that of maintaining integrity of the trailing accelerometer cable. Additional tests, incorporating other types of cable and payout methods, are scheduled for the first of FY 1968. Improved sabot designs have been investigated by firing models (approximately 1/10 scale) from the 3-in. air gun. Figure 2 shows a design which appears to be very attractive based on performance and cost. Necessary modifications to the 22-in. air gun to accommodate the requirements of CSAD tests are being considered.

In furtherance of the efforts to improve instrumentation, a commercially available impact-resistant charge amplifier is being evaluated. This amplifier is placed on the specimen carriage along with the amplifier, thus placing the trailing wire in a low impedance circuit and rendering it less sensitive to spurious

electrostatically induced signals. Preliminary test results are quite encouraging. The investigation of impact-resistant transmitters suitable for telemetering shock data is continuing; copies of reports of work done under the LRC penetrometer program have been obtained and are being studied.

During this report period 196 high-impact tests were performed utilizing the aforementioned facilities. These tests supported the high-impact development efforts listed in Table 1.

Table 1. Test conducted during report period

Item		Number of tests
High-impact communications subsystem technology		74
Antennas	13	
Traveling wave tube amplifier	32	
Crystal	21	
Miscellaneous	8	
High-impact battery technology		13
Mechanical response to high impact		21
High-impact test equipment development		88

Note that in the last two categories, only tests supporting the test equipment investigations are reported. Cooperative development tests involving particular ruggedized equipment development tasks are reported in the appropriate equipment category.

PUBLICATIONS DURING REPORT PERIOD

Papers Presented at Meetings or Symposia

1. Lonborg, J. O., "Current Status of Design Accomplishments for Shock Levels of 10,000 g," ASME Design Engineering Conference, New York City, May 16, 1967.

JPL SPS Contributions

1. Taylor, S. G., "22-Inch Air Gun for High Impact Testing," SPS 37-44, Vol. IV.

ANTICIPATED PUBLICATIONS

None.

Fig. 1. Sling shot

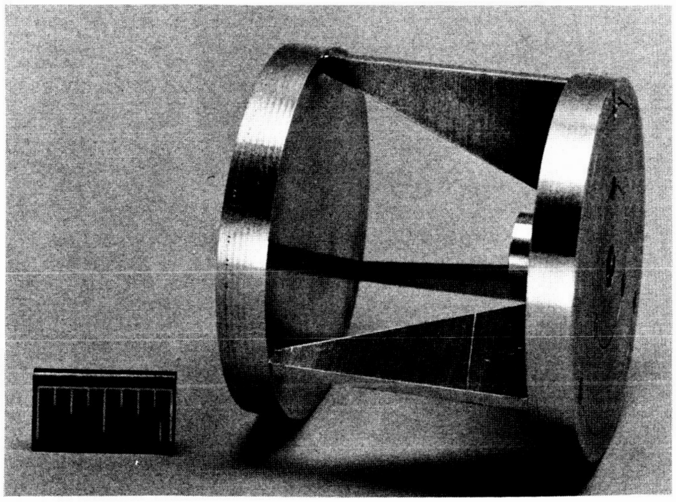


Fig. 2. Scale model (1/10) of 22-in. air gun sabot

HIGH-IMPACT ELECTRONIC EQUIPMENT PACKAGING TECHNOLOGY

NASA Work Unit 186-68-10-06-55
JPL 384-65901-2-3570

E. R. Bunker, Jr.

OBJECTIVE

A long-range objective of this work unit is to design and develop spacecraft subsystem and subassembly electronic packaging and cabling technology that will allow the development of hard-lander capsule equipment that will reliably survive high impact with no damage or degradation. This effort will continue to develop the technology for "typical" subsystem electronic packaging and to develop standard packaging techniques. The resultant configurations are to be able to meet a broad spectrum of hard landing capsule electronic subsystem packaging requirements.

CONNECTOR HIGH-IMPACT TEST

High-impact tests were made of the type D connectors with steel retainer shells electron-beam welded together. Small aluminum blocks were used to distribute the stress caused by impact over a larger area around the mounting screws. These blocks can be seen in Fig. 1. Three connectors were mounted in the three perpendicular axes as described in previous semiannual reviews. This test setup is described in JPL TM 33-296, Vol. I.

A minor change was made in the monitoring of continuity through the connector pins using the four-channel chatter detector. In the two series of runs before, all of the pins in a given connector were wired in series and monitored by one of the channels of the chatter detector so that all four connectors were monitored. In the present tests, the pins in each connector were divided into four zones, i.e., approximately equal numbers of pins on each side and the center divided in half lengthwise. The pins of each zone were connected in series and connected to one channel of the chatter detector. During the sequence of seven shock levels from 2500 to 10,000 g, only one connector was thus monitored at a time. The connections to the chatter detector were moved to another connector at the conclusion of each shock sequence and the sequence repeated. Thus, each connector type was exposed to a total of 21 different impacts ranging from 2500 to 10,000 g. Type D connectors of 9-, 15-, 25-, and 50-pin configurations were tested. In Fig. 1 which shows the 50-pin connectors after the 21 impact tests, no significant mechanical damage occurred. A slight bending of the mounting screws used in mounting the horizontal connector on the right was noted. Therefore, these screws were replaced after each test. This problem would be eliminated by hardened steel screws which would be used in the high-impact configuration. At levels above 5,000 g, the connector mounted with the impact parallel to the pins showed a momentary open condition. No significant pattern was observed as the opening occurred apparently randomly in any of the four zones. After each impact, the reset button on the chatter detector was pressed, and the detector reset indicating that the momentary open occurred only during the few milliseconds of impact. No other connector configuration or position showed this momentary open condition up to 10,000 g.

Three sets of tests also allowed a rudimentary investigation into the effects of high impact on cabling. Referring to Fig. 3 of JPL TM 33-296, Vol. I, the cabling from the connector is clamped rigidly by clamps on the outer edge of the test jig base. From the failures that occurred, it appeared that the weight of the cable between the connector and clamp caused a pulling action on the connector which ruptured the shell. To eliminate the possibility of failure caused by this cantilevering, the clamps for the cable were moved inboard closer to the connectors as shown in Fig. 1 of the last semiannual report for this work unit. In Fig. 1 of this section it can be seen that the clamps were moved to the outer edge as before. This time, however, the cabling from the connector was routed down to the base, tied down with a clamp, and then routed to the outboard clamp as shown. This simulates a high-impact cable harness clamped close to, but far enough from, the connector to allow disengagement from the chassis mounted connector.

During all of the tests, no failures occurred in the wiring or the soldered connections to the connector pins. From these results, it appears that a cable harness consisting of type D connectors and Teflon-covered wiring, as was used in these tests, would be capable of withstanding high-g levels.

HIGH-IMPACT STICK MODULE CONFIGURATION

The stick module approach of mounting flat packs and discrete components, developed under "Microelectronic Packaging Advanced Development," NASA Work Unit 125-25-03-02, would appear to have promise in a high-impact configuration. A connector stick module was developed under the subject work unit to facilitate the interface between the sticks and the cable connectors. A photograph of this connector stick module is shown in Fig. 2. A drawer was designed to accommodate the connector stick module and the other sticks. This resulted in a rigid configuration which would appear to be capable of surviving high impact in any direction while having a convenient slide-in drawer shape. This configuration is shown in Fig. 3.

In FY 1968 the objective has been modified to produce functional electronic subassemblies which are capable of withstanding high-impact conditions. In addition, these subassemblies must withstand the requirements of sterilization. In accordance with this, further work will be done on the fabrication and testing of high-impact connector and cable subassemblies. Further work will be done on the type D connectors using reenforced and welded shells that are nonmagnetic to satisfy the requirements for spacecraft systems that prohibit magnetic materials. It is further planned to integrate functional modules into a complete package capable of withstanding sterilization and high-impact environments as would be encountered by a hard landing capsule on a planet.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

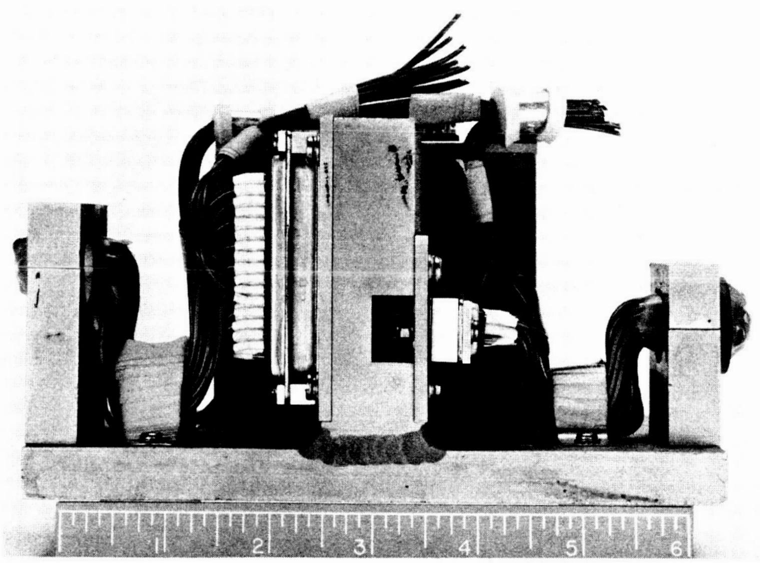


Fig. 1. High-impact test configuration

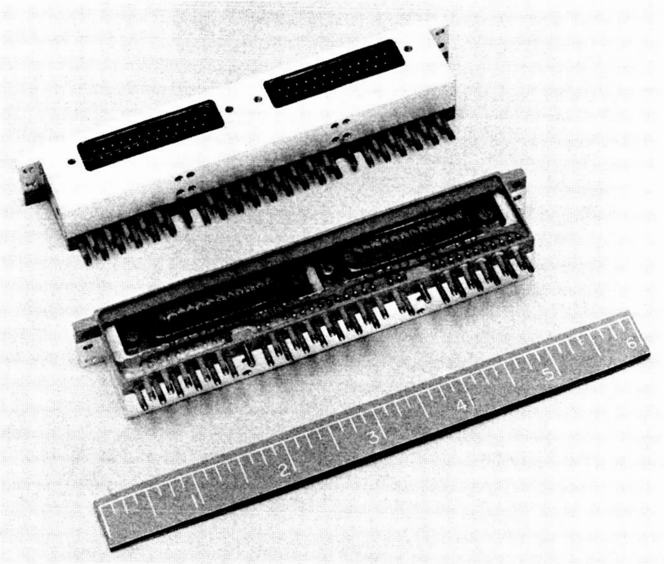


Fig. 2. Connector stick module

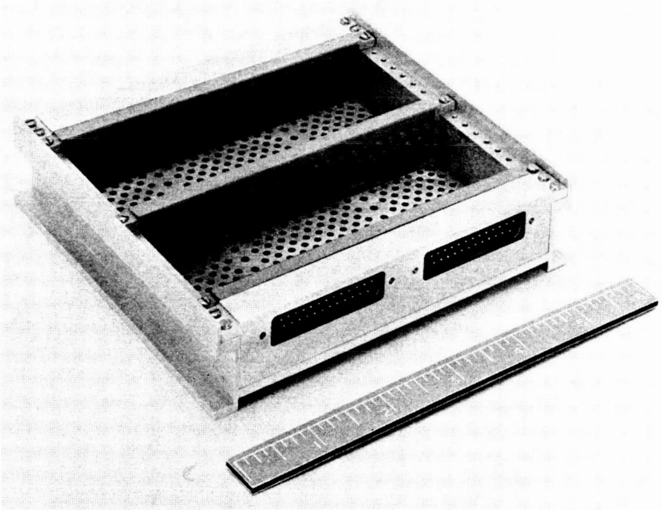


Fig. 3. Stick module chassis

MODULAR ELECTRONIC PACKAGING ADVANCED DEVELOPMENT

NASA Work Unit 186-68-10-09-55
JPL 384-66601-2-3570

Earle R. Bunker, Jr.

OBJECTIVE

A long-range objective of this work unit is to develop, qualify, and reduce to practice advance packaging and cabling concepts on technology which are initially generated either by industry or by "Electronic Packaging Advanced Development," NASA Work Unit 125-25-03-01.

CONCENTRIC ELECTRODE WELDER

Using magnet wire as an electrical interconnect medium has required the development of new soldering and welding technology. For magnet wire welding to be feasible, it must be welded through the insulation without a previous stripping operation. Procedure in the past has been to use a heated welding electrode to melt the insulation, and when contact was made with the terminal a welding pulse would then be applied to the junction. The small size of the magnet wire used (No. 32 -- 0.008-in. diam), required a careful, precise alignment of the welding electrodes with the terminals so that the wire would not slip out during the heating phase of the operation.

To overcome this alignment problem a concentric electrode welder was proposed. This consisted of a hollow (concentric) tip through which the insulated wire would be pulled. The resistance at the tip would serve as a heating element which would remove the insulation from the magnet wire in the area under the tip. When the penetration of insulation was completed the heating current would be switched off and the weld pulse would then be applied across the joint, between either parallel or opposed gap electrodes, thereby completing the weld. The welding electrode would then be moved to the next terminal thus exerting a pull on the previous weld joint and thereby giving a built-in pull test during fabrication.

Tentative specifications were prepared and vendors contacted who might have the necessary capability to develop equipment for this system for which a budget of $25,000 was allotted. During the investigation into insulation materials which would be optimum for this application, it was found that a hard magnet wire coated with Teflon would allow the insulation coat to split neatly to each side of the conductor when cold-deformed by properly shaped electrodes. Since no heat was required this would result in a much simpler system than originally proposed. To obtain a clean, uncontaminated separation it is necessary that the wire be much harder than copper. Therefore, nickel wire insulated with an extruded Teflon coating was ordered so that this concept could be further evaluated, but date after date for promised delivery of this wire has been made and broken by the vendor. Meanwhile, various electrode configurations have been analyzed and studied to determine the optimum shape for splitting the Teflon insulation.

In the first half of FY 1968, pending delivery of the wire by the vendor, this cold electrode method of welding magnet wire will be evaluated, and if the approach

appears promising further work will be done. If this approach does not work, further development of the heated concentric electrode configuration will be resumed.

PLANAR FLAT-PACK INTERCONNECTION

Based on the results of the study made for "Microelectronic Packaging," NASA Work Unit 125-25-03-02, the feasibility of substituting a two-sided printed circuit board with auxiliary voltage and ground busses for a multilayer printed circuit board was investigated further. The study showed that a two-sided board could be used to achieve the same number of interconnections that had previously required a nine-layer multilayer printed circuit board. This study was based on the techniques used in designing the printed conductor ring harness board that was substituted for the conventional cable harness on the Mariner C spacecraft. The original nine-layer multilayer board used in Mariner 1969 is shown in Fig. 1. Boards were fabricated from the artwork and flatpacks installed as shown in Fig. 2 which is a mockup of the final configuration. The separate voltage and ground connection busses were then added and are shown in Fig. 2. Upon receipt of the types of flatpacks used in the present multilayer board, an operational board will be fabricated. Comparison tests between this board and the nine-layer multilayer board will be made in a functional subsystem to check the operational characteristics and feasibility of the two-sided design.

WIRECON HEADER RE-DESIGN

A widening usage of the Wirecon header for cordwood packaging of electronic components indicated some desirable improvements, especially in the fabrication of the header itself. The present Wirecon risers are fabricated from flat stock by chemical etching procedures. The cross-sectional area of the risers must be maintained within close tolerances to facilitate welding to the component leads. The risers had to be bent and molded into the header, which also resulted in excessive expense to the vendor. To overcome these and other objections which were uncovered by a survey of various users, the Wirecon III header was designed. In the new header the plastic part is molded first without the risers, which are added later. After the risers are inserted, they can either go straight upward or be bent outwards to enable a wider than normal module to be fabricated. The risers themselves will be fabricated from wire which allows a circular cross section to be maintained with much greater accuracy than the rectangular cross section of the chemically etched risers. This in turn facilitates welding schedules and simplifies fabrication techniques.

ADVANCED MODULAR ELECTRONIC ASSEMBLY CONFIGURATION

The advanced electronic equipment assembly concept described in the previous semiannual report has been fabricated and qualified for use on Mariner Mars 1969. A careful review of the construction features and the use of this packaging approach in the actual spacecraft application is being reviewed, so that improvements in the concept can be made for future applications.

THICK FILM FACILITY

Continued emphasis on subminiaturization and weight reduction has resulted in the development of several new techniques for the production of microcircuits. Of these the thick-film hybrid approach offers the greatest promise for use in low-quantity, short-lead-time circuits.

Briefly, the thick-film circuit is constructed by depositing special inks onto ceramic substrates by the silk-screen process. Subsequent firing results in a passive nestwork to which other discrete active or passive components can be attached.

An investigation of equipment, techniques, and components is now in progress. The main purpose of this investigation is not to produce hardware but to learn the technology involved in order to benefit procurement and make significant contributions in the field.

The advanced development thick-film facility has been described in part under "Microelectronic Packaging," NASA Work Unit 125-25-03-02.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

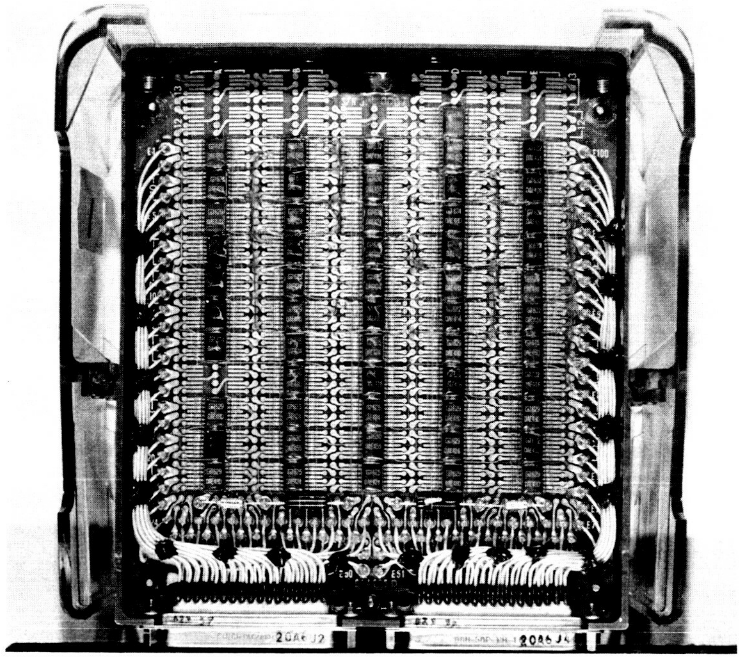


Figure 1. Nine-layer board

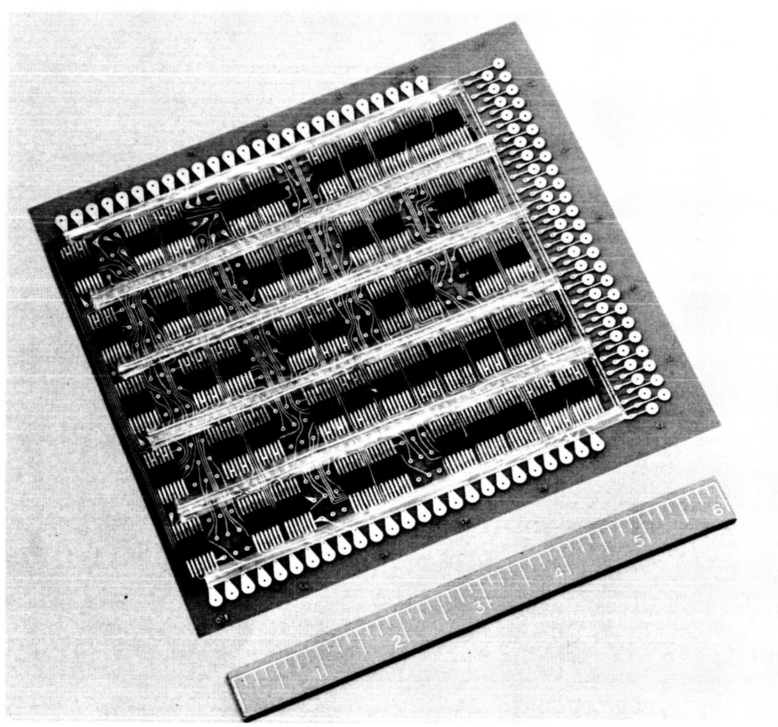


Figure 2. Two-sided board

EVALUATION AND QUALIFICATION OF CONNECTORS AND WIRES

NASA Work Unit 186-68-10-10-55
JPL 384-67201-2-3570

R. W. Lester

OBJECTIVE

The overall objective of this work unit is to assure the availability of connectors, wires, and accessories suitable for use on future spacecraft. Specific long-range objectives are (1) to develop evaluation and qualification procedures and criteria which will provide high confidence in the reliability and functional capability of connectors, wires, and accessories accepted for specific spacecraft and missions, (2) to conduct evaluation and qualification tests to determine the acceptability of parts for projected spacecraft designs and missions, and (3) to remedy inadequacies in available products by developing improved or new connector and wire parts.

WIRE

A draft of a general specification for qualification testing requirements for wire and cable accessories has been completed. It is planned that the completed document, together with detail requirements specifications, will be used to determine the acceptability of candidate wires for use in spacecraft applications. A variety of wires with Kapton insulation have been ordered for evaluation.

If wires with insulation of this material prove satisfactory for flight use, it may be possible to achieve a weight savings in excess of 10% of the wire weight. In addition, the results of materials testing under another work unit indicate that Kapton has excellent outgassing characteristics and is capable of withstanding decontamination and sterilization exposures without significant degradation.

It is planned that the general qualification specification, together with the detail specification, will be completed in the first quarter of FY 1968. Wire testing is to commence in the second quarter.

MULTIPIN CONNECTORS

During the next fiscal year, evaluations and qualification testing of multipin electrical connectors, which appear to offer advantages over those now in use, are planned. In the past, almost all of the connectors used on JPL spacecraft have had solder-pot contacts. It is intended that in addition to investigations of flight-type connectors with solder contacts, which have recently become available, a study of crimp-contact connector performance and reliability, which was started about three years ago, will be reactivated. This study was discontinued because of a lack of available manpower and funds.

Possible advantages of crimp-contact connectors are (1) volume and weight savings, (2) more potential suppliers, (3) shorter fabrication schedules and reduced manhours, and (4) greater flexibility in correcting errors or in making changes because individual contacts are replaceable. Despite the potential gains from using

crimp-contact connectors, because of the history of JPL successes with solder contact connectors in many spacecraft, convincing performance and reliability data are considered requisite to recommending a change in connector types.

CAPSULE SYSTEM ADVANCED DEVELOPMENT

A basic design for the separation connectors interfacing the lander and the planetary entry system capsule, as well as between the capsule and the remainder of the spacecraft, is to be developed. It is expected that additional support will be given to this program in the areas of connector and cable evaluation testing and design effort.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

MICROCIRCUIT WELDING ADVANCED DEVELOPMENT

NASA Work Unit 186-68-10-11-55
JPL 384-68301-2-3510
V. F. Lardenoit

OBJECTIVE

It is the broad objective of this program to evaluate welding techniques applicable to spacecraft welded electronic packaging. The specific areas to be studied in this work unit will be the applicability of nonresistance welding techniques to future microcircuit joining requirements. These include electron beam, laser, and other nonresistance heating methods. This work unit is in support of "Modular Electronic Packaging Advanced Development," NASA Work Unit 186-68-10-09 which is carried out by the JPL Electromechanical Engineering Support Section (357).

PROGRESS

Originally, this program consisted of two phases: one covering a literature and vendor survey and the other including tests. It was decided to exclude the second phase from the program due to increased manpower commitments required by the Mariner Mars 1969 spacecraft.

During the past 6 mo, the survey phase was continued on electron beam and laser welding with emphasis placed on electron beam applications.

Although the electron beam welding technique has been used for aerospace structural welding, its use in microcircuit welding has occurred over more recent years. Basically, the electron beam technique exhibits the same attractive characteristics as the laser, such as high energy, small spot sizes (i.e., small heat-affected zone), accessibility, and precise alignment; and both are noncontact processes. Significant differences between the two processes include (see Refs. 1-4):

(1) The laser can be used in any environment that passes light.

(2) Outgassing of the material does not affect laser performance.

(3) The laser, being an optical system, has a flexibility advantage.

(4) The electron beam is not sensitive to reflectivity.

(5) Electron beam welding is accomplished in a vacuum environment, thus the joint is not contaminated.

The electron beam, like the laser, offers many possibilities in usage. Due to the necessity of a vacuum environment to perform the weld process, it becomes advantageous to utilize a multiple-chamber system to reduce pumpdown time. Additionally, the control achievable makes the electron-beam process conducive to automated production. Electron beams have been evaluated and used in such microcircuit applications as automated welding units (see Refs. 5 and 6) and for automated processing of thin-film components (Ref. 7). In the latter, the electron

beam is used as a vaporization source in a deposition chamber and also as a trimming device. Based on evaluation of joint strength, weld resistance, thermal shock, extreme ambient temperature, and vibration tests, electron beam welding has been demonstrated to be a statistically predictable, reliable joining process (Ref. 8).

In the previous semiannual report, some disadvantages of lasers and potential applications of lasers were covered. Improvements are continually occurring in laser design, since it is still a relatively recent development. Some of the disadvantages have been taken into account in improving basic laser welder design. Manufacturers provide for protection of the operator's eyes in their equipment and have improved on their original approaches (Ref. 9). In addition, output energy control has been improved upon by properly controlling temperatures in the laser head, including ruby rod and flash tubes. Also, new design of flash tubes has been investigated (Ref. 9). Recycle time has been improved to the point where firing rate has now become a function of operator dexterity (Ref. 9). Since the laser is an extremely high-energy light source, the reflecting characteristics of the materials being joined become an important factor. This property must be taken into account when welding, especially in the case of dissimilar metals exhibiting gross differences in reflectance. Techniques to alleviate this problem have been postulated, such as coating the material to be welded with a low-reflectance coating, but have not been extensively evaluated.

The survey or electron beam and laser techniques applied to microelectronics joining has revealed the attractive characteristics of each device as well as potential and actual production applications. Both processes have undergone considerable development and are still being further improved. In their present state of development, it appears that lasers and electron beam welders are being used only where large production rates warrant their higher initial and operating costs. Laboratory evaluations have demonstrated the advantages of electron beam and laser equipment, however, their high costs prohibit usage on a small scale except in certain applications where conventional techniques are not capable of performance. As the high costs are reduced with further improvement of equipment, these fusion welding techniques will become even more attractive. Even if costs are not reduced to those of presently used techniques, the increased demands of future spacecraft for greater packaging densities and higher reliability will necessitate the use of lasers or electron beam welding techniques.

FUTURE PLANS

Due to funding constraints in FY 1968, this program will not be continued; however, it is planned to resume this effort in FY 1969. It is expected that adequate manpower will be available to update the survey at that time. In addition, an evaluation could be conducted to evaluate the strength, electrical characteristics, joint reliability, and metallurgical characteristics of welded joints prepared by electron and laser beams.

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2. Maguire, T., "Microwelding—Laser or Electron Beam," Electronics pp. 23-25, July 5, 1963.

3. Slemmons, J. W., and Howell, J. R., "Joining Concepts for Microelectronic Systems," presented at Annual Conference of Engineers, May 1964.

4. Farrell, W. J., "Electron Beam and Laser Techniques for Joining," Materials Science and Technology for Advanced Applications, Vol. 2, pp. 451-510, American Society for Metals, February 1964.

5. Garibotti, D. J., and Ullery, L. R., Jr., "Production-Line Packaging of Solid-State Circuits," Electronics, pp. 73-79, September 7, 1964.

6. "Electron Beam Welding Cuts Separate Joining of Computer Memory," Materials Engineering, p. 23, April 1967.

7. von Ardenne, M., Schiller, S., and Heisig, U., "Automated Electron Beam Processes Thin Film Components," Electronics, pp. 110-115, March 7, 1966.

8. Garibotti, D. J., and Lane, W. V., "Microminiature Electron Beam Welded Connections," Welding Journal, pp. 417s-427s, September 1963.

9. Myers, J. H., "Design of a Production Worthy Laser Microwelder," Proceedings of the Electron and Laser Beam Symposium, April 6-8, 1966.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Lardenoit, V. F., "Microcircuit Welding Advanced Development," SPS 37-43, Vol. IV, pp. 127-128, February 28, 1967.

ANTICIPATED PUBLICATIONS

JPL Technical Memorandums

1. Lardenoit, V. F., Laser and Electron Beam Welding for Microcircuit Application.

ADVANCED MECHANISMS
NASA Work Unit 186-68-12-05-55
JPL 384-68201-2-3550
M. B. Gram

OBJECTIVE

The objective of this work unit is to examine certain mechanisms, concepts, and components on an advanced development basis in order to minimize later project problems and to better answer questions concerning best mechanization for a given set of requirements. Specifically, landed capsule orientation devices, instrument deployment booms, and a spacecraft chemical heater have been singled out for advance development investigations.

CAPSULE ORIENTATION

With increasing frequency space missions are being considered which embody landing of a survivable payload in foreign terrain. Following landing it is necessary to orient the capsule and to deploy instruments in order to maximize acquisition of meaningful information. Figure 1 depicts eight of many schemes considered for orienting capsules. Schemes 1 through 7 require as the first step in the orientation sequence, the removal of impact-limiting material; these schemes are also predicated on the conventional spherical shape capsule. Schemes 1 through 5 make use of unfurling or extendible springs and inflatable elements, which through deployment cause the capsule to become righted. Deployable segments of the capsule shell proper are used in scheme 6 for righting. Scheme 7 consists of inflating a toroid-shaped structure initially stowed in an equatorial groove of the capsule. Inflated, the structure produces a bistable disc-shaped configuration. The bistable feature necessitates dual instrument deployment masts with only the up-side mast being extended following orientation. Figures 2 and 3 show a prototype version of this scheme at beginning and completion of orientation.

Orientation scheme 8 makes use of a disc-shaped capsule to which is permanently affixed impact-limiting material. One of two instrument deployment masts is erected following orientation as in scheme 7. Advantages of this scheme are: (1) impact-limiting material need not be removed, (2) capsule orientation is completely passive, obviating mechanical hardware, and (3) packaging efficiency is high for the disc-shaped capsule. Principal disadvantage is the necessity for dual instrument deployment masts with an ensuing weight and volume penalty.

A capsule employing the disc-orientation scheme has been built, drop-tested, and is reported under NASA Work Unit 186-68-10-03-55. Whereas drop tests have not been made in a full spectrum of possible soils, validation of the orientation scheme is felt to have been accomplished from tests performed to date. No additional developments are intended on capsule orientation during the forthcoming fiscal year.

DEPLOYABLE INSTRUMENT MASTS

In keeping with often-arising requirements to deploy several ounces of instruments from a landed capsule, a survey was made of existing deployable structures.

Typical capsule requirements call for a mast deployment height of 6 to 10 ft with a deployable load of 4 oz in a wind environment of 35 mph (earth equivalent).

The mast shown in Figs. 4 and 5 consists of a spiral-coiled steel element stowed in a cylindrical base. Upon release the spring element spontaneously assumes its relaxed configuration resulting in a strong stiff support member. An impact-ruggedized and sterilizable version of this mast is currently under development. Future effort will be to develop latching and cable payout devices and to demonstrate sterilizability and impactibility of the composite mechanism.

Where requirements preclude the use of radio frequency opaque materials for deployable masts because of interference with antenna patterns, an inflatible instrument mast becomes attractive. Such a mast, developed under this work unit is shown in Figs. 6 and 7. The tube is 2 in. diam, fabricated from 1-mil Mylar. Pressures less than 5 psig cause deployment and provide sufficient structural integrity to meet wind loading conditions. Feasibility has been demonstrated; no further development is intended.

SPACECRAFT CHEMICAL HEATER

Studies of Mars landed capsules wherein night survivability is requisite, have introduced requirements for a class of spacecraft heaters which at present do not exist. Required are the combination of characteristics of controllability, high output per weight, and high heat delivery rate. In competition with nuclear heat sources and electric batteries, only the chemical reaction heater possesses the potential for meeting these requirements.

Toward the end of demonstrating the feasibility of high-performance chemical reaction heaters, concurrent chemical and mechanical investigations were undertaken. Chemical effort was aimed at finding chemical reactants which were hyperbolic, storable, and sterilizable. The chemical reaction must be highly exothermic and give rise to combustion products lending themselves to disposal or storage. These requirements are best met with crystalline boron and (liquid) chlorine trifluoride. Laboratory tests have borne out handbook values of heat yield and have demonstrated the chemical suitability of the reactants.

Mechanical effort has been expended to develop a temperature sensing and metering unit with high sensitivity for effective temperature control, and which is sterilizable, compact, impactible to 2500 g, and does not require electrical power for its operation. The two sensing metering valves shown disassembled in Figs. 8 and 9 are under development and appear to meet all requirements. Respectively, they employ a snap-acting bimetal disc and a silicon rubber pellet as the active sensing and actuating element. In response to temperature these elements meter the flow of liquid reactant to the combustion zone by positioning a Teflon diaphragm relative to a flow port.

A proposed configuration for a 2-kWh heater utilizing boron and chlorine trifluoride is shown in Fig. 10. Future work will be directed toward demonstrating functional utility of a chemical heater with integral temperature sensing and control in a sterilizable and impactible configuration.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

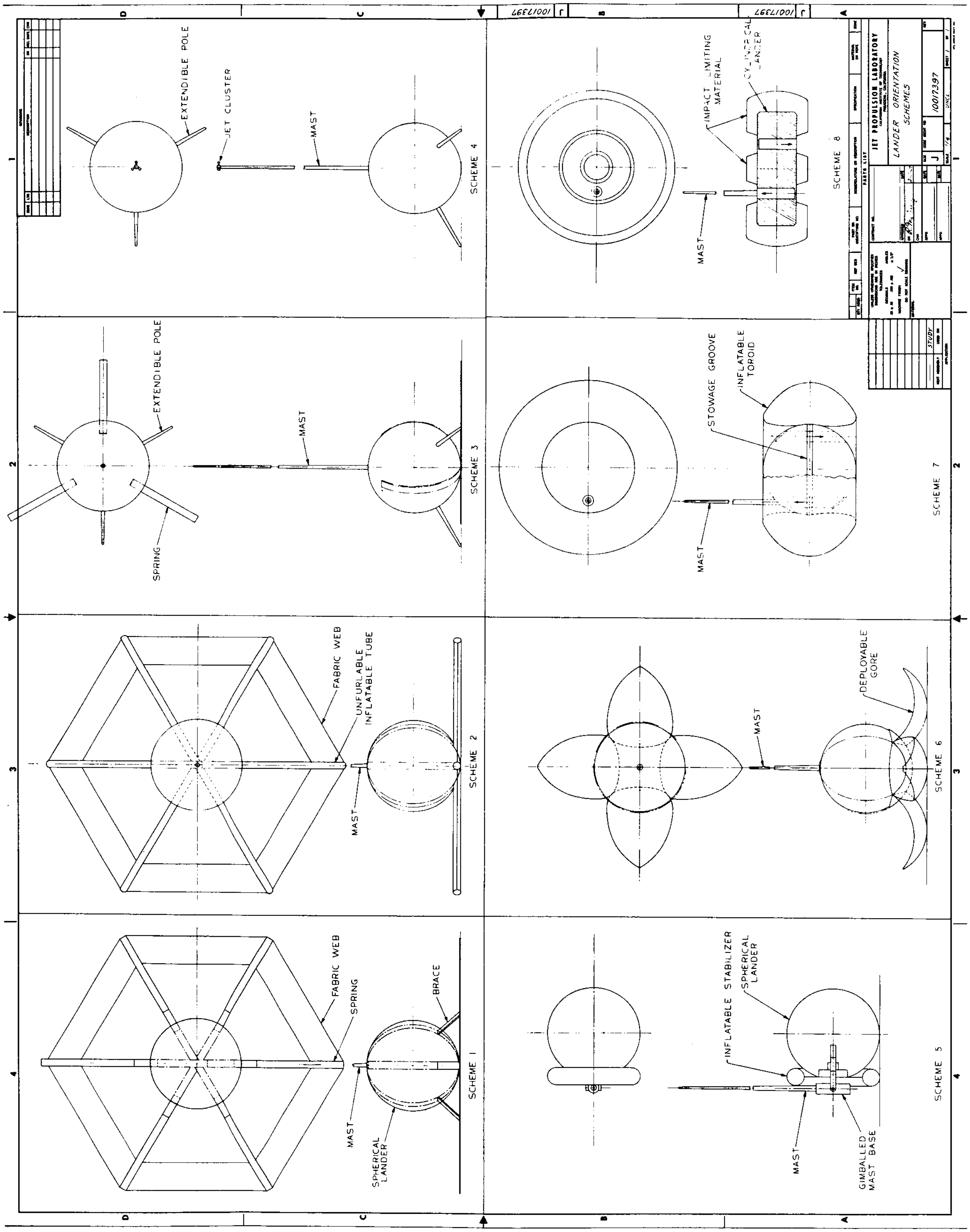

Fig. 1. Landed capsule orientation schemes

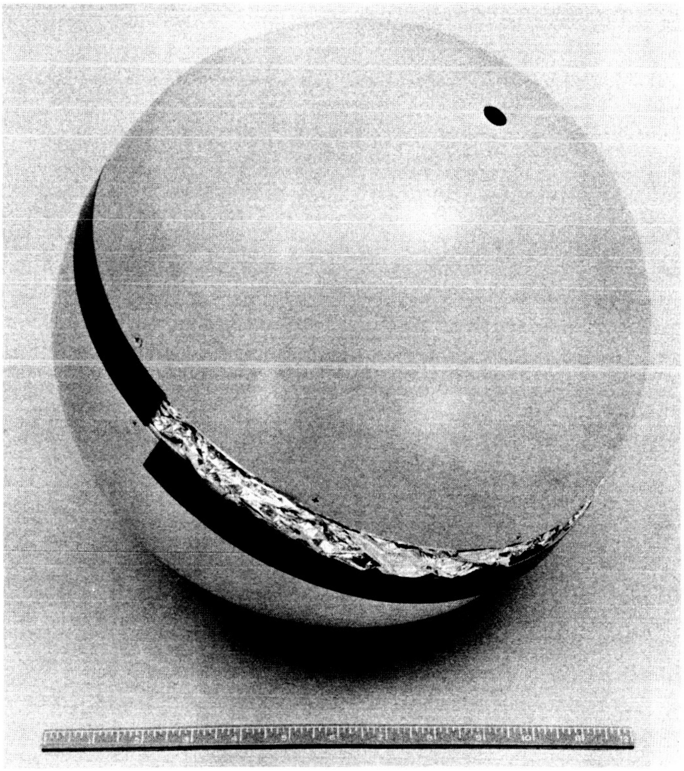

Fig. 2. Capsule with inflatable orientation structure stowed

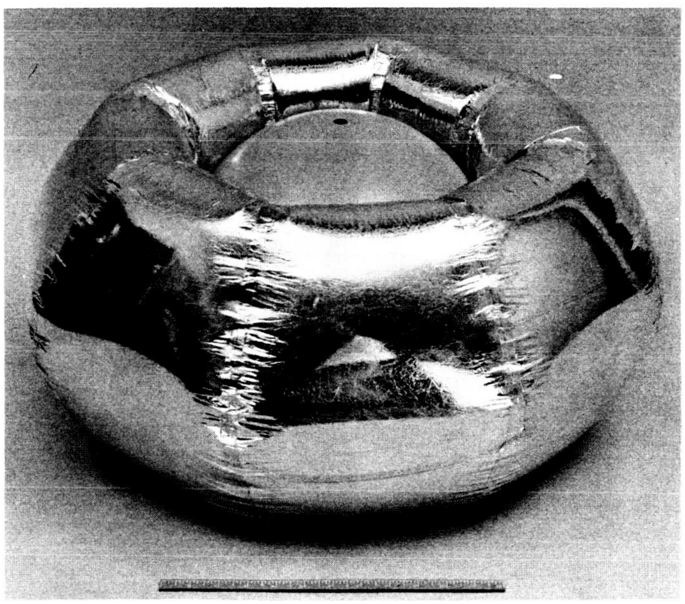

Fig. 3. Capsule with inflatable orientation structure deployed

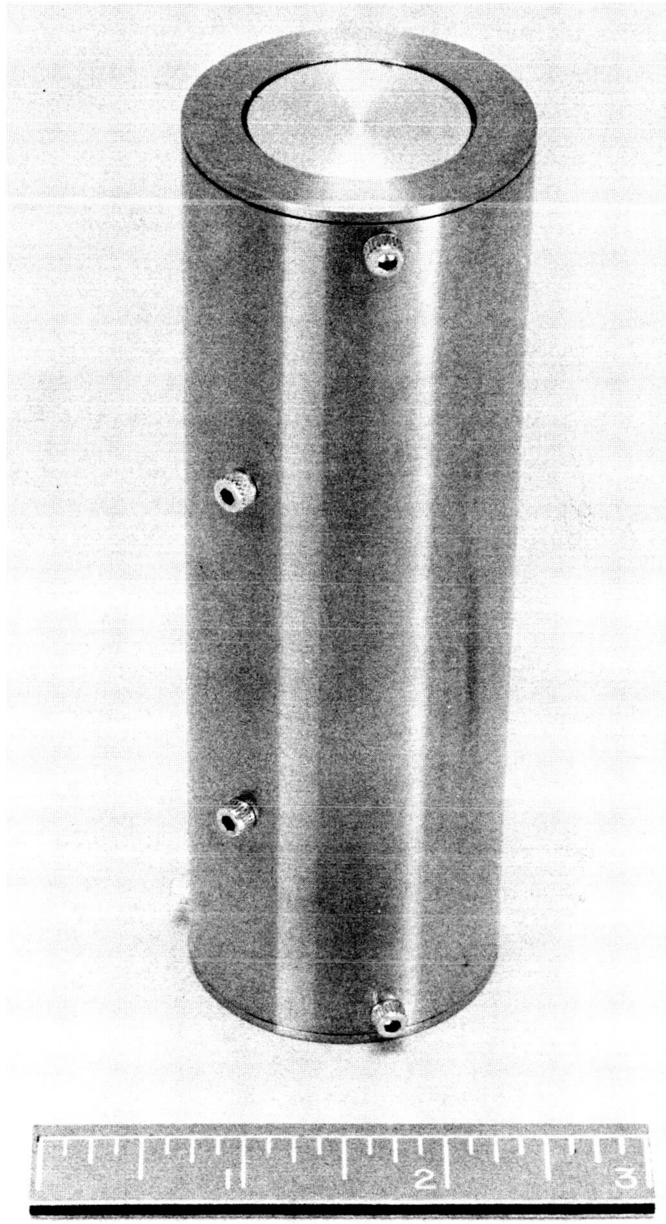

Fig. 4. Steel spring instrument mast-stoyed

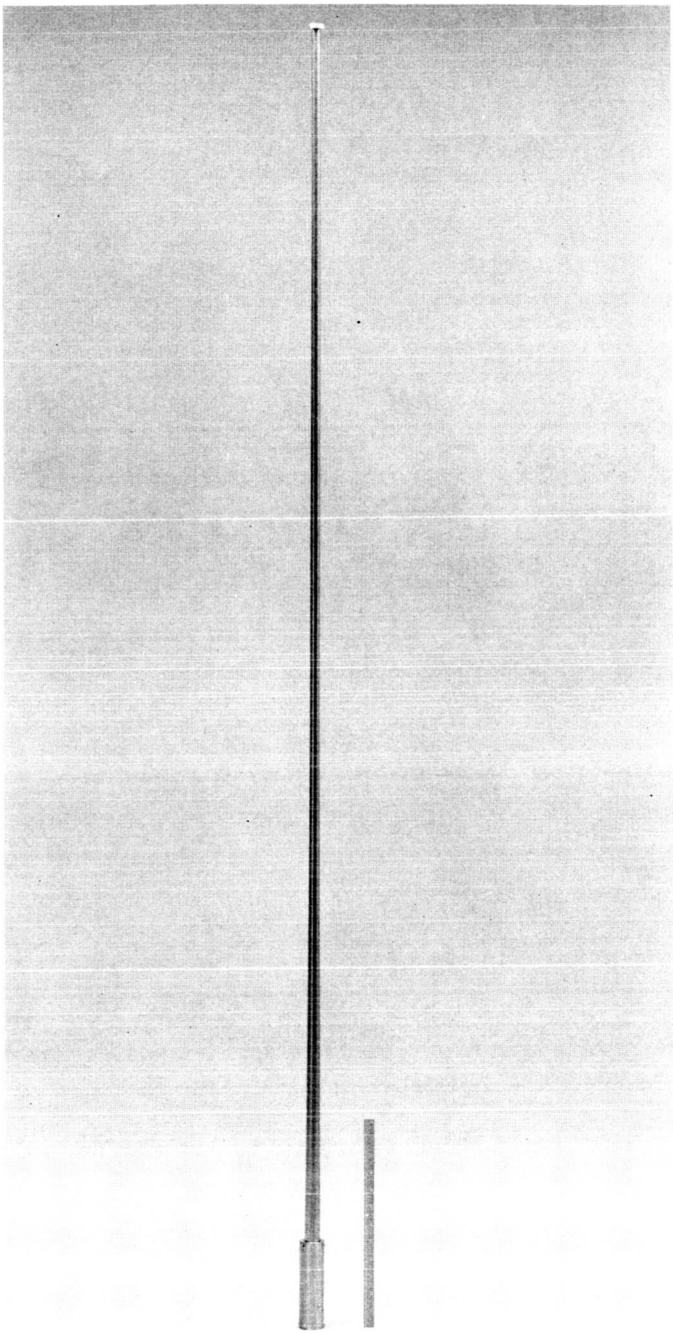

Fig. 5. Steel spring instrument mast-deployed

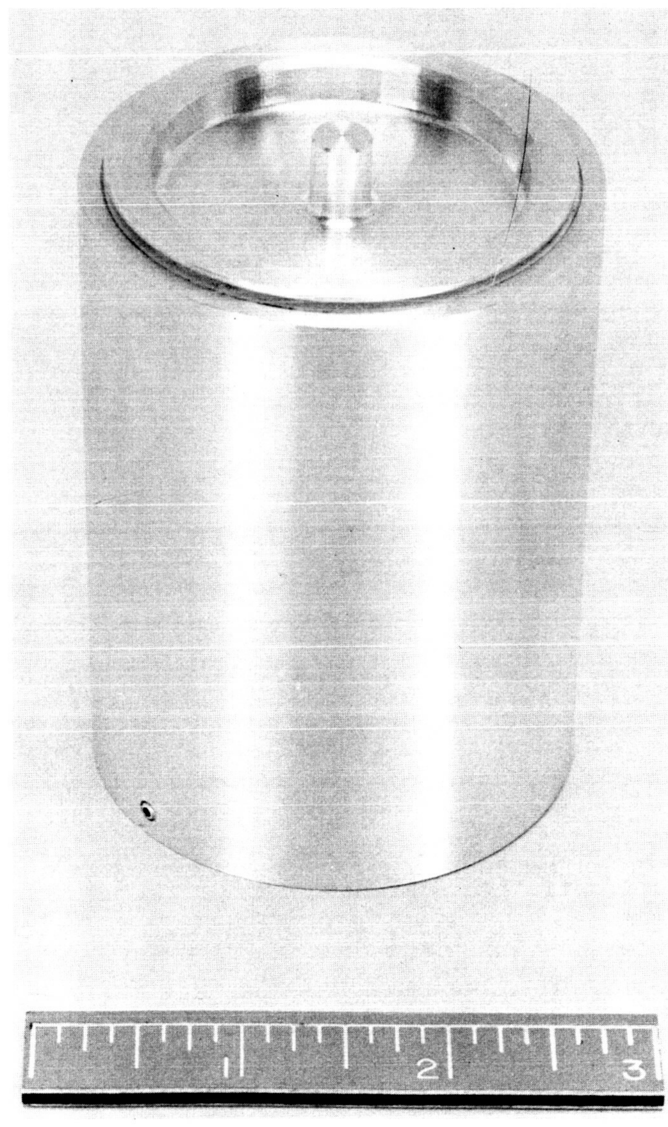

Fig. 6. Inflatable instrument mast-stoyed

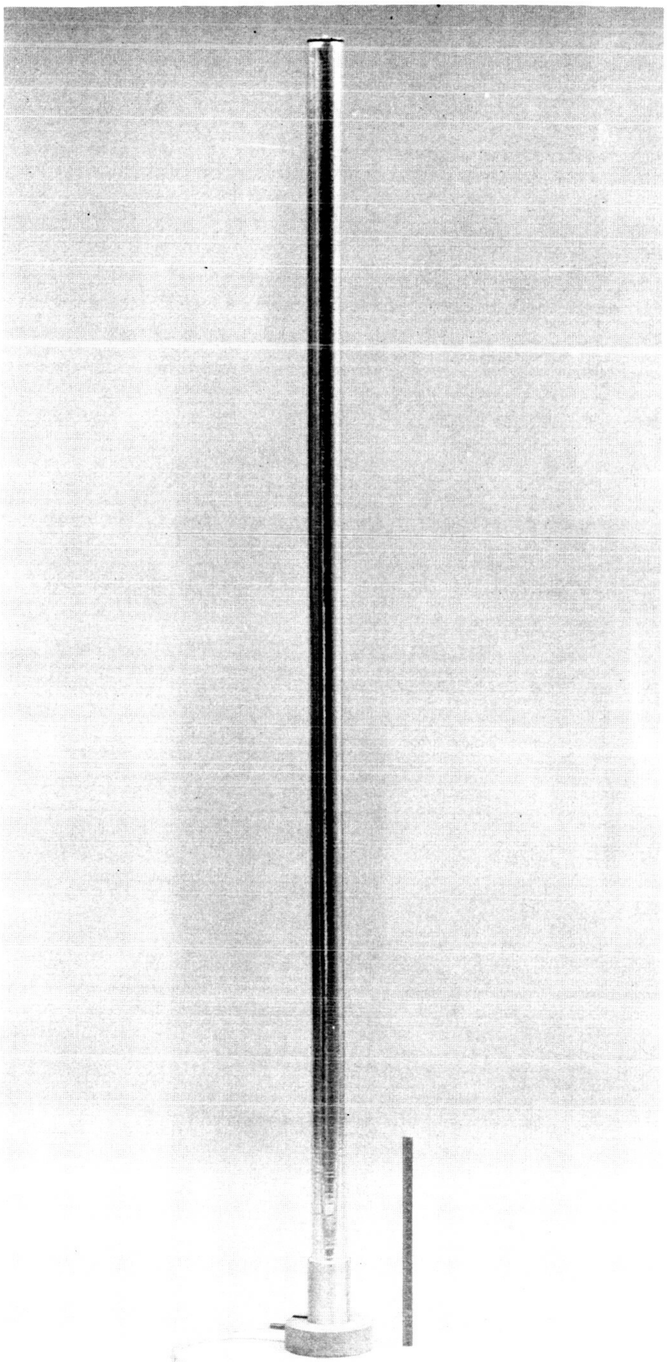

Fig. 7. Inflatable instrument mast-deployed

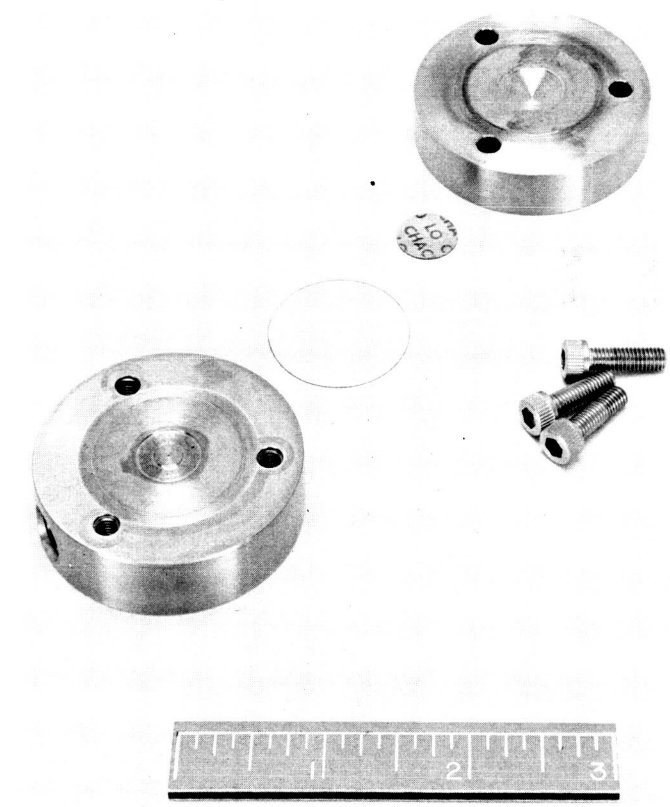

Fig. 8. Chemical heater sensing metering value utilizing bimetal disc element

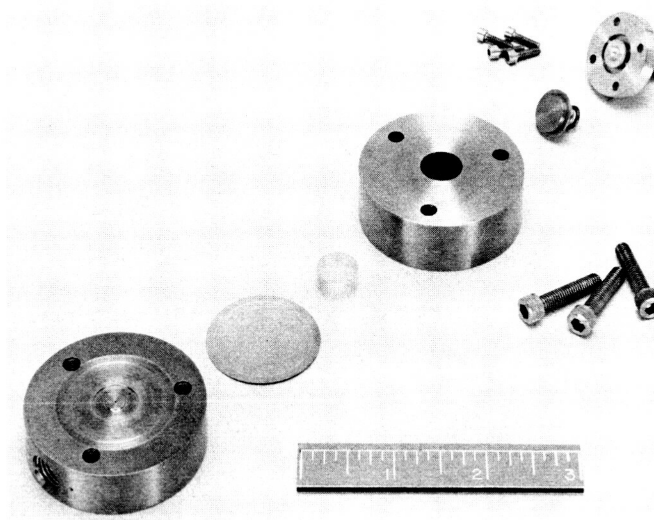

Fig. 9. Chemical heater sensing metering valve utilizing temperature-expanding element

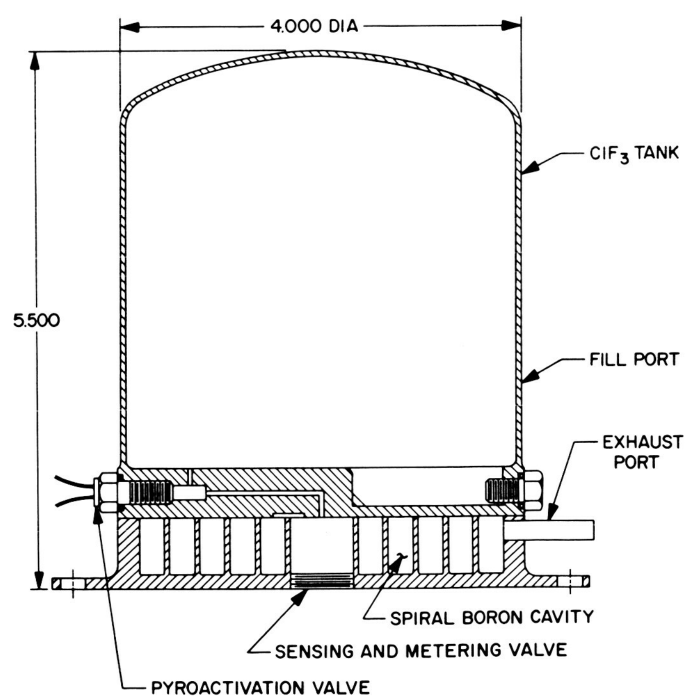

Fig. 10. Spacecraft chemical heater

SPACECRAFT MATERIALS EVALUATION

NASA Work Unit 186-68-13-03-55
JPL 384-62701-1-3820
J. Moacanin

OBJECTIVE

The objectives of this work unit are as follows: (1) define materials and design parameters which are relevant for the use of cellular plastics, i.e., foams, as encapsulants for operation in space environment, (2) find materials best suited for proposed applications, and (3) relate changes in mechanical properties of urethane elastomers to chemical changes which occur during heat sterilization.

FOAM ENCAPSULANTS

A series of rigid closed-cell foams varying in both formulation and density were prepared, and a systematic study of their dielectric strength was carried out. Cell structure and dimensions were examined by microscopic observations. The following main experimental results were obtained.

For a given specimen, breakdown voltage is proportional to the square-root of the thickness (Fig. 1). This result demonstrates the importance of specifying the test-specimen thickness when reporting dielectric strength values for foams. Cell size (Fig. 2) and flaw-free structures are major factors that determine dielectric strength. Because of anisotropy in cell dimensions, dielectric strength will vary with the direction of test. Density is a minor factor as shown in the previous semiannual report.

All the experimental observations can be interpreted in terms of a dielectric failure that is initiated by gas discharges within the foam cells.

The parameters which determine the dielectric strength of a foam are summarized in order of their importance as follows:

(1) Homogeneity of structure. Properties of a given foam can be optimized only if the cells are uniform in size, and the content of voids or multi-connected cells is kept at a minimum.

(2) Cell geometry. Highly symmetrical cells will minimize the anisotropy of properties. Small cell size will improve strength.

(3) Gas content and type. Reducing gas pressure decreases strength. Fluorocarbons lead to much higher strength than does CO_2.

(4) Polymer distribution in the cell. It is advantageous to increase the window thickness at the expense of struts. Also, conditions during foaming should minimize stressing of windows.

(5) Density. The optimum density is 6 to 10 lb/ft^3. In this range the foam has adequate mechanical strengths, and optimization of all the above parameters is easier to achieve. It is difficult to manufacture homogeneous higher density foams free of voids.

Previously developed miniaturized pressure transducers were used for measuring internal gas pressure during foam formation. For confined foaming the peak pressure exceeded 10 psig. These results demonstrate the necessity to carefully select foaming conditions for packaging of sensitive electronic components.

Consulting services on foam problems were provided to JPL Section 336 in connection with a Voyager lander antenna.

MECHANICAL PROPERTIES OF STERILIZABLE URETHANE ELASTOMERS

This work is being carried out in support of the development of sterilizable propellants. The main experimental techniques will involve the use of a creep-measuring device and a stress relaxometer. Both instruments were constructed under NASA Work Unit 329-30501-1. Measurements have been initiated on a urethane elastomer based on a saturated polybutadiene prepolymer.

FUTURE ACTIVITIES PLANNED

It is planned to complete during the forthcoming period the work on foam encapsulants. The assembly of a corona detector will be completed. The experimental study will center on the determination of the voltage of incipient corona as function of cell structure, flowing gas, and gas pressure.

The work on urethane elastomers will emphasize studies on the behavior in the sterilization temperature range, i.e., around 135°C. Chemical changes will be correlated with those in the mechanical behavior in order to provide a rational basis for optimizing sterilizable formulations.

PUBLICATIONS DURING REPORT PERIOD

Meetings and Symposia Papers

1. Moacanin, J., "Electrical Properties of Rigid Urethane Foam," and Cuddihy, E. F., "Outgassing of Rigid Urethane Foam," invited lectures, Cellular Plastics Technology Conference, Wayne State University, Detroit, Michigan, May 1-5, 1967.

Open Literature

1. Cuddihy, E.F., and Moacanin, J., "Diffusion of Gases in Polymeric Foams," J. Cellular Plastics, 3, No. 2, 73 (1967).

JPL SPS Contributions

1. Cuddihy, E. F., and Moacanin, J., "Method for Estimating the Temperature Dependence of Foam Diffusion Constants," SPS 37-44, Vol. IV.

ANTICIPATED PUBLICATIONS

JPL Technical Reports

1. Moacanin, J., Farrar, J., and Einhorn, I., Dielectric Strength of Rigid Urethane Foam (in press).

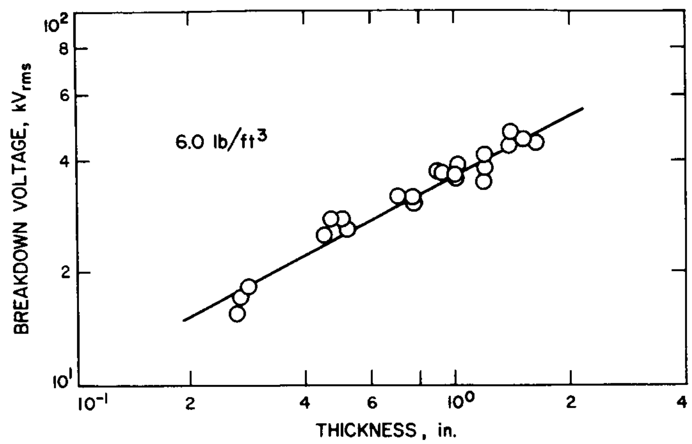

Fig. 1. Dependence of breakdown voltage on sample thickness (Eccofoam)

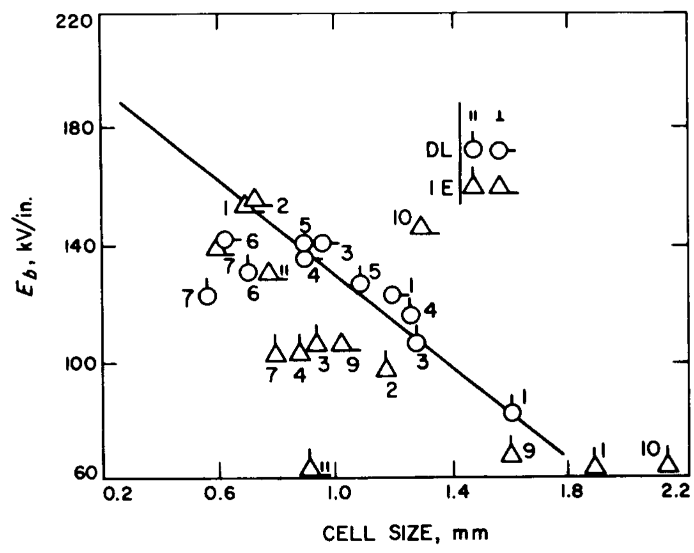

Fig. 2. Variation of dielectric strength with cell size

POLYMERS FOR SPACECRAFT APPLICATIONS

NASA Work Unit 186-68-13-04-55
JPL 384-68401-2-3510

E. L. Cleland

OBJECTIVE

The broad objective of this work unit is to compile a comprehensive list of preferred polymeric materials for spacecraft fabrication that are the most suitable for use in a vacuum-thermal environment. The approach toward this objective in FY 1968 will be (1) to screen selected commercial polymeric products by using Micro-VCM techniques to determine the potentially useful materials, (2) to subject the screened candidate materials to further qualification tests, (3) to determine the effects of short- and long-term exposure to thermal-vacuum environments on key polymeric properties, (4) to characterize the behavior of polymeric products by investigating the effects of initial and postcure on their weight loss and VCM contribution, and (5) to attempt to correlate all test data for development of acceptance standards which can be used in preparing materials specifications.

PROGRESS

This program was initiated in the fourth quarter of FY 1964 as a stimulus to aid in the development of material specifications and qualifications of polymeric materials for the JPL Spacecraft Materials Guidebook. A contract (JPL Contract 950745) was awarded to Stanford Research Institute in June 1965.[1] The contract was modified,[2] and supplemented in the third quarter of FY 1967 by a commitment of $59,960 from FY 1967 research and advanced development in this work unit.

More than 400 polymeric products have been screened for potential use by techniques which were innovated or advanced during this work. Among the new technologies announced by the contractor during the overall work of this program is a method and apparatus (Fig. 1) for doing a sensitive and rapid procedure for screening polymeric materials. It is the micro-VCM technique which determines the total weight-loss and the volatile condensable material (VCM) of a finely divided polymeric sample after a 24-h exposure at 125°C and 10^{-6} torr. This type of data gives an 80 to 100% estimate of the maximum weight-loss and maximum VCM content that is inherent in a specific polymeric product. The limits of acceptance for further evaluation of polymeric products have been established as ≤1% weight-loss and ≤0.1% VCM. Listed in Table 1 are examples of functional polymeric products that have met these criteria.

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[1] "Development of Specifications for Polymeric Materials," Stanford Research Institute, Menlo Park, Calif.; $66,756. Subsequent supplements to this contract from project funds expanded the funding to $281,147 and the performance to February 1967.

[2] "Polymers for Spacecraft Applications," Stanford Research Institute, Modification No. 4, to extend performance to July 31, 1967.

Many of the accepted materials were evaluated further using the macro-VCM technique, an innovation also developed and announced by the contractor. In the macro-VCM technique, a sample of 3 to 10 g provides engineering information on the deposition and reevaporation of VCM as a function of time, and also weight-loss data. This method is used also to evaluate materials that have marginal qualifications but that are unique and critical for spacecraft applications. In Table 2 are listed some typical materials and their macro-VCM evaluations.

The possibility of upgrading marginal materials, as well as improving acceptable materials, has been done chiefly through studies on the effect of initial and postcures on materials. As ancillary methods, analyses of the VCM by mass spectrometry and infrared techniques have given clues as to the effectiveness of thermal conditioning of polymeric materials. The evaluation of other key properties of the materials has been done in long-term storage experiments and in the comprehensive test program as outlined in Fig. 2. In essence, the long-term storage effects give basic data on the relative rate of induced crosslinking versus degradation through scission of the polymer chain. This information, in turn, relates to the best end-use application of the material for long-duration space flights, e.g., 8000 h to Mars. The comprehensive test program, a recent part of the overall effort, is designed to determine changes in the pertinent properties of polymeric materials after a decontamination treatment followed by a thermal vacuum exposure.

FUTURE PLANS

This task will end on July 31, 1967 with the contractor's final report being available in September 1967.

The work under this task will be merged with that of "Sterilizable Polymers," NASA Work Unit 186-58-13-02-55.

PUBLICATIONS DURING REPORT PERIOD

Contract Reports

1 to 6. Muraca, R. F., et al., Polymers for Spacecraft Applications, Stanford Research Institute, Monthly Technical Progress Reports Nos. 31 to 36, January 15 to June 15, 1967 (JPL Contract 950745).

ANTICIPATED PUBLICATIONS

Contract Reports

1. Muraca, R. F., et al., Polymers for Spacecraft Applications, Stanford Research Institute, Monthly Technical Progress Report 37, Available July 15, 1967 (JPL Contract 950745).

2. Muraca, R. F., et al., Polymers for Spacecraft Applications, Stanford Research Institute, Final Report, Available September 15, 1967 (JPL Contract 950745).

Table 1. Typical polymer products recommended for further qualification based on micro-VCM values

(wt-loss, 1.0% or less; VCM, 0.1 wt-% or less)

Application	Product	Basic polymer
Adhesives	Armstrong A-2/A	epoxy
	Armstrong A-2/E	epoxy
	Eccobond 45/15	epoxy
	Eccobond 55/9	epoxy
	Eccobond solder 56C/9	epoxy
	Epon 901 B-3	epoxy
	Epon 917	epoxy
	Epon 931 A/B	epoxy
Circuit boards	Micarta H-1754	epoxy-glass
	Micarta H-2497	epoxy-glass
	Micarta 65M25	epoxy-glass-copper
Coated fabrics	Armalon 98-101	fluorocarbon-polyamide
	Fairprene 80-series	fluorocarbon-polyester
	TB5-PTFE	fluorocarbon-glass
Films and sheets	Kapton 200XH667	polyimide
	Kapton 300XHF929A	polyimide-fluorocarbon
	Mylar type 500A	polyester
	Tedlar A130WH	polyvinyl fluoride
	Tedlar 100BG30TR	polyvinyl fluoride
	Tedlar 100BG30TL	polyvinyl fluoride
Foams	Stycast 1090/9	epoxy
	Stycast 1090/11	epoxy
Hardware and structural	Delrin (most)	acetal
	Diall (all)	diallylphthalate
	Epiall 1914	epoxy-glass
	Lexan (all)	polycarbonate
	Micaply G-284	epoxy-glass
	Micarta H-17690	epoxy-glass
	Micarta H-5834	phenolic-glass
	Micarta 20201-2	silicone-glass
	PPO 681-111	polyphenylene oxide
	PPO 531-081	polyphenylene oxide
	P-2300	polysulfone
	P-7395-121-2	polysulfone

Table 2. Macro-VCM determinations: seal and gasket materials

Material / Polymer-type (Mfr Code)	Property	Hours of exposure at 125 °C and 10^{-6} torr: 24	48	96	336	Remarks
SE-3604	wt-loss, %	0.28	0.24	0.50	0.57	Postcured 4 h/ 205 °C; dimensions: 2 x 1.5 x 0.084 in.
silicone (SIS)	VCM, wt-%	0.12	0.14	0.18	0.29	
Hycar 520-67-108-1	wt-loss, %	1.19	1.29	1.24	1.48	Samples as received; dimensions: 6 x 1 x 0.08 in.
acrylic (BFG)	VCM, wt-%	0.10	0.05	0.12	0.15	
Viton A4411A-990	wt-loss, %	0.44	0.46	0.53	0.61	Samples as received; dimensions: 6 x 1 x 0.08 in.
vinylidene fluoride-hexafluoropropylene (SIS)	VCM, wt-%	0.02	0.02	0.01	0.01	
Teflon FEP 500A	wt-loss, %	<0.01	<0.01	<0.01	<0.01	Samples as received; dimensions: 6 x 1 x 0.02 in.
fluoroethylene-propylene (DUE)	VCM, wt-%	<0.01	<0.01	<0.01	<0.01	

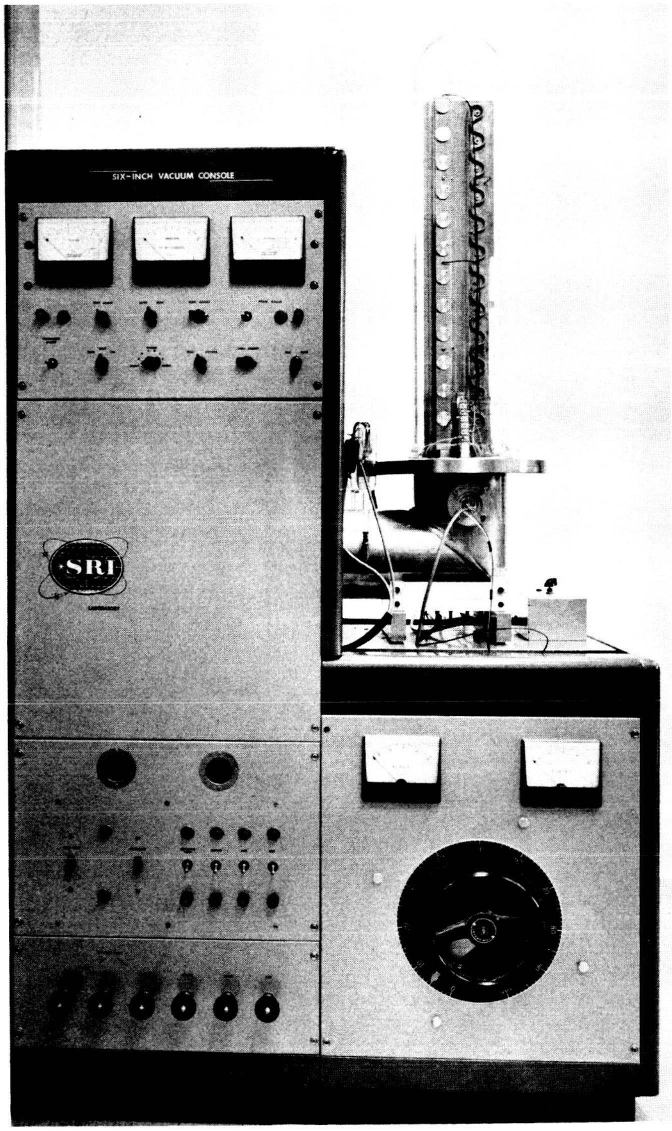

Fig. 1. Micro-VCM apparatus

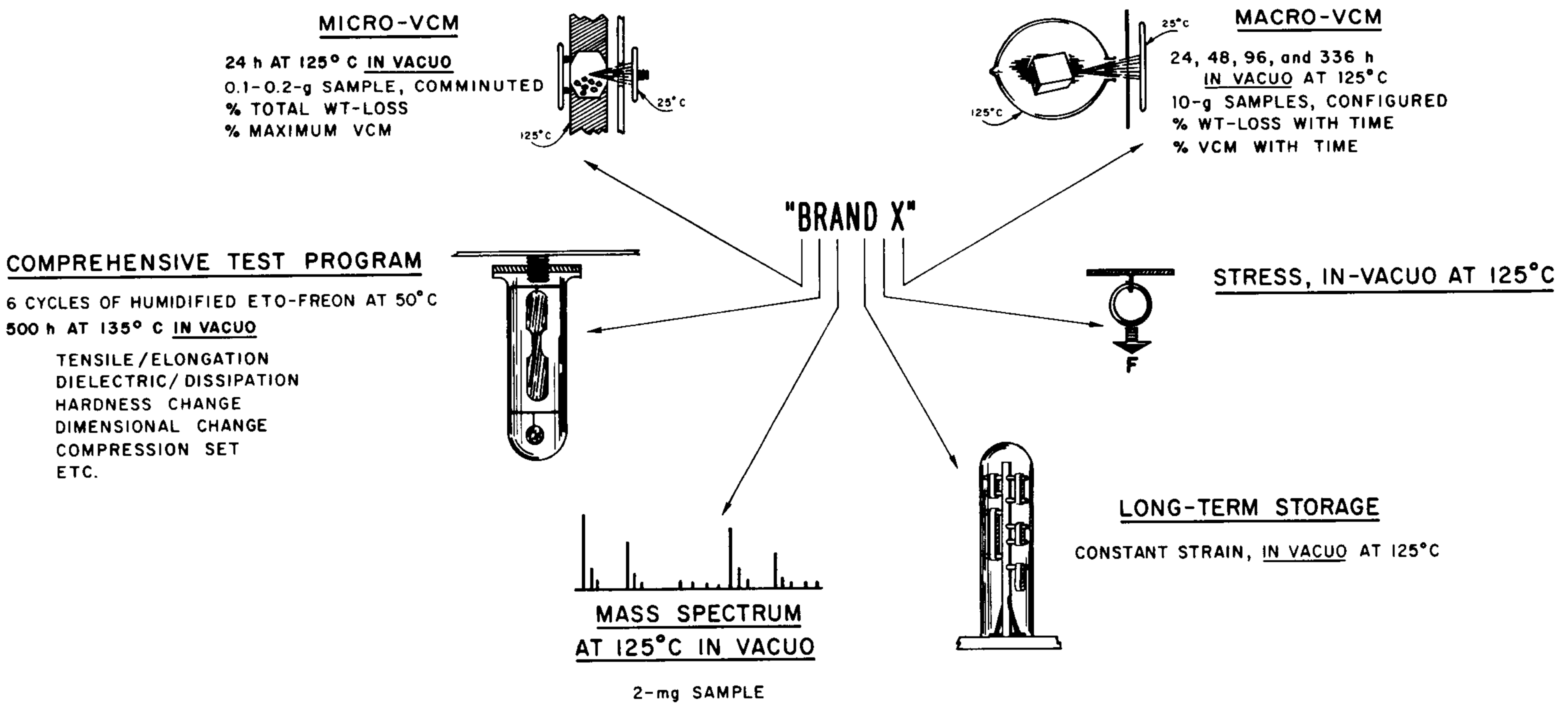

Fig. 2. Examination of polymeric samples

SPACECRAFT RELIABILITY (186-70)

ELECTRONIC COMPONENT SCREENING METHODOLOGY

NASA Work Unit 186-70-01-04-55
JPL 384-00401-2-3540

W. B. Bartel

OBJECTIVES

The objectives of screening methodology investigations are to provide improved methods for screening electronic piece parts utilized in spacecraft assemblies. The resulting improved methods will be used for in-house acceptance testing of nonspecification-controlled parts. Where feasible, such methods will also be incorporated into part procurement specifications for acceptance testing by the parts' manufacturers.

The effort is divided into subtasks for consistency with part types and characteristics being investigated.

TRANSISTOR LIFE TEST METHOD EVALUATION

A typical screening test for transistors includes a burn-in at elevated temperatures with derated power applied. Several manufacturers have suggested that the burn-in can be accomplished as effectively at a room ambient temperature but at a higher power level. The ambient burn-in would substantially reduce the complexity and cost of the burn-in by eliminating ovens and the associated controls that go with it.

This effort will consist of a comparative evaluation of room ambient and high-temperature burn-in methods. A matrix test will be utilized to optimize stress conditions. The stresses applied to the various matrix elements will include temperature, voltage, current, and power in various combinations.

An engineering test plan was prepared, and an RFQ was issued in early April to four potential contractors. All four of these returned a no-bid.

The test plan has been modified and reissued for bids to five potential contractors. Four new bidders and one on the original list have been solicited. The test specimens have been delivered. The contract effort should begin late September 1967, and end February 1968. A complete report is expected by April 1968.

DEVELOPMENT OF MOSFET RELIABILITY TEST AND SCREENING METHODOLOGY

The MOSFET transistor is a recent development in the transistor field. It has features which are of interest to us for many applications. These include a high input impedance comparable to vacuum tubes, it can be operated at very low power levels, and it tends to simplify transistor circuitry. The device is also somewhat simpler to manufacture.

The MOSFET is, however, highly sensitive to transients encountered in testing and handling. For example, static electricity from one's clothing may destroy the device if it is not properly protected. Being a new device, no proven testing methods have been established.

Purchase orders for parts and testing were placed with Fairchild (PO 433989, $12,000) and Siliconix (PO 433990, $15,000) in early April. The test plan developed jointly with the vendors includes evaluation.

(1) Gate voltage stresses the breakdown region.

(2) Voltage-temperature stresses.

(3) Oxide purity tests.

(4) Temperature cycling effects.

Promising screening test methods will be verified by an operating life test.

Correlation samples have been reviewed, identified (Transistor Internal Structure Sheets prepared), and measured. The first three of eight phases has begun.

The contracted tests are scheduled for completion by March 18, 1968.

AUTOMATIC TRANSISTOR TESTER PROCUREMENT

An automatic transistor tester was procured, primarily for support of NASA Work Unit 186-70-01-08. This tester is replacing an existing TACT tester. The TACT is tending to obsolesence and is also limited in that it will not adequately handle the more advanced transistors such as MOSFET and high-frequency devices. The new tester will also support project transistor testing.

The tester, a Fairchild Model F-500, was delivered and installed on November 1, 1966. A 2-mo operator training and checkout schedule was concluded with assistance of the manufacturer. The checkout consisted of monitoring the performance of the tester on a daily basis by repeated tests of a selected group of transistors. One minor malfunction was noted during this time, a drift in a timing circuit. This malfunction was corrected, and the tester is operational.

DEVELOPMENT OF POWER PULSE METHOD OF SCREENING RESISTORS

A screening method for resistors is being investigated, wherein a short duration power pulse is applied to the part with resistance variations monitored during the pulse period. Current screening methods include temperature cycling, TC measurements, and burn-in. This effort will demonstrate feasibility by screening parts by both methods and compare performance in a life test.

A contract for this effort was awarded in May 1966, to Mid Continent Laboratory for $49,000. Delivery of test specimens delayed start of testing to September. At present, screening tests by the two methods have been completed. The follow-on life test is currently in progress.

Preliminary data after 500 h of life indicates that the power pulse method has the capability of detecting potential failures with a high degree of consistency. However, final evaluation of results must await completion of the life test.

The only catastrophic failures during the life test were the Ultronics Model CC10A power wire-wound resistors. Failures were due to overrating on the part of the manufacturer. All units were removed from the tests, and failure analysis will follow. The life test is scheduled to be completed on the remaining units by August 1, 1967. Tab runs are presently being prepared to determine Delta R failures after 500 h of life.

INVESTIGATION OF TRANSISTOR BACK BIAS VERSUS POWER LIFE TEST

The objective of this subunit was to determine the effectiveness of a back bias at elevated temperature in comparison with the currently used power burn-in for low-level transistors.

The approach was to subject a sample of parts to increasing steps in temperature with a constant bias voltage. A second sample was subjected to increasing steps of bias voltage with temperature constant. These two samples were then subjected to a normal burn-in. A third sample was subjected to a burn-in first followed by a back-bias test.

The contractor has completed the test effort and the results have been partially evaluated. The evaluation indicates that a high temperature back-bias test is significantly more effective in detecting defective parts than a burn-in. The method appears to be particularly suited for detecting so-called channeling defects. The specimens used demonstrated an average failure rate of about 14%. Those groups which were exposed to the back-bias test followed by a power burn-in experienced about 14% failures in back-bias and about 0.5% in burn-in. In the group, wherein the order of tests was reversed, about 6% failed in burn-in and 8% in back-bias.

The effectiveness of the back-bias test appears to be a linear function of voltage and a weak exponential function of temperature. Therefore, the best results would be obtained at the highest safe test temperature and voltage. Transistors can be safely tested at 200°C. However, at this temperature, test carriers for transistors, become costly. Consequently, a tradeoff must be made between test temperature, cost, and test time.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

Subtask 8 — Review of Models and Methods of Accelerated Testing (FY 1967 Funding)

The purpose of this subtask is to thoroughly review the various models and methods that have been proposed for accelerated testing of electronic parts. Particular attention is being given to determining the underlying and often unstated assumptions associated with these models and assessing whether these assumptions appear to be valid.

In February 1967, JPL Contract 951727 was established with the Research Triangle Institute of Durham, North Carolina, and work on this subtask commenced. To date, a literature search has been performed identifying 202 items for review and reviews have been completed for 19 of these items. During the 12-mo duration of this contract, it is estimated that 250 to 300 separate pieces of literature on accelerated testing will be reviewed. A summary report on this effort will be prepared late in August 1967, and a final report will be completed during the third quarter of FY 1968.

Subtask 9 — Resistor Matrix Test (FY 1967 Funding)

The purpose of this effort is to investigate the behavior of one type of wire-wound resistor as a function of power and temperature during life test.

This effort was definitized by Test Procedure 651-66-07 and RFPs were issued during March 1967. The proposals were received and technically evaluated, and a cost analysis has been completed. Final contract negotiations are now being carried out. It is estimated that testing will commence during August 1967 and will be completed during August 1968.

Subtask 10 — Diode Matrix Test (FY 1967 Funding)

The purpose of this effort is to investigate the behavior of one type of silicon diode as a function of power and temperature during life test.

This effort was definitized by Test Procedure 741.10-07 and RFPs were issued during March 1967. The proposals were received and technically evaluated, and a cost analysis has been completed. Final contract negotiations are now being carried out. It is estimated that testing will commence during August 1967 and will be completed during August 1968.

Subtask 11 — Accelerated Test of Integrated Circuits (FY 1967 Funding)

This effort is intended to establish a feasible method for performing an accelerated test program on one type of digital integrated circuit. The circuit is of sufficient complexity to preclude direct increases of power and temperature as is frequently done with discrete devices and therefore requires that some less conventional approach be formulated.

This effort has been defined in a Statement of Work, RFPs have been issued, proposals have been received and evaluated, and final contract negotiations are under way. It is estimated that a contract will be established during August 1967, and that all work will be completed during August 1968. The purpose of this subtask is to study accelerated testing methods and procedures applicable to the rapid evaluation of integrated circuits.

Subtask 12 — Zener Diode Comparative Screening Test (FY 1967 Funding)

In this test, nine separate groups of TRW 1N4661 zener diodes will be subjected to different electrical/thermal screens. All devices will subsequently be life-tested under identical conditions. The resulting data will allow establishment of relationships between the response of each group to the initial stress and the subsequent life-test behavior. Comparisons of parameter stability and reliability during life test will be made between groups.

Contract 951725 for $20,883 has been established with Librascope of Glendale, California, to perform this effort. The necessary test fixtures are being fabricated and testing will commence early in the first quarter of FY 1968.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

Papers to be Presented at Meetings or Symposia

1. Klippenstein, E., Hanks, C., and Hamman, D., "Effects of Nuclear Radiation as Part of the Temperature - Vacuum - Power - Environment," IEEE Conference on Nuclear and Space Radiation Effects, July 10-14, 1967.

JPL SPS Contributions

1. Klippenstein, E., "Effects of Nuclear Radiation on Electronic Parts," SPS 37-44, Vol. IV, in publication.

JPL Technical Memorandums

1. Mills, P. M., Final Report on a Ceramic Capacitor Accelerated Life Test Program, TM 33-328.

FAILURE MECHANISMS IN ELECTRONIC COMPONENTS

NASA Work Unit 186-70-01-07-55
JPL 384-00701-2-3540

L. W. Wright

OBJECTIVE

The objective of this task is to support the advanced development of electronic subassemblies by effecting an improvement in the reliability of critical electronic parts through the investigation and elimination of failure mechanisms. During FY 1967, emphasis has been placed on the investigation of materials and processes employed in electronic parts and on investigation of failure analysis techniques for integrated circuits.

ACTIVITIES DURING REPORT PERIOD

Subtask 2 — X-Radiation Effects Test (FY 1965 Funding)

JPL Contract 951369 has been completed, and the contractor's final report has been received. Additional data analysis and part failure analysis is still under way at JPL. The analysis, to date, has not indicated any substantial effects due to the levels of radiation applied during this test. However, during the program some failures and parametric trends were observed. The 2N910 transistors exhibited a relatively large percentage of leakage current failures due to surface inversion and current gain tended to generally drift downward. In the groups of 2N1132 transistors, current gain tended to drift upward while both noise voltage and saturation voltage drifted downward. The FD600 diodes were in general quite stable, and the only parametric failures observed were devices which were no more than 20 mV outside of tolerance on forward voltage drop.

Subtask 3 — Study of Semiconductor Microcracks (Scanning Electron Microscopy)

Preliminary investigations of methods for detection of microcracks in semiconductor devices indicated that the single most promising method was scanning electron microscopy. After discussions of scanning electron microscopy with persons actively engaged in such work at IBM, Westinghouse, RCA, GSFC, and the University of California at Berkeley, a procurement action was initiated to obtain a scanning electron microscope. Delivery of this instrument is expected during the second quarter of FY 1968. It is anticipated that this instrument will be of benefit in the investigation of microcracks as well as in the study of other types of surface and bulk defects in semiconductor devices.

Subtask 4 — Analysis of Gas Ambient in Electronic Parts (FY 1966 Funding)

The purpose of this subtask is to establish a means for analyzing the gas content within electronic parts. Once established, this technique can then be easily employed whenever required in the investigation of failed devices.

This effort covered by PO BY384833 has been progressing satisfactorily. A test chamber for the puncturing of test specimens and division of their ambient gases

into two separate samples has been fabricated and tested. To date, the chamber has been used in analyzing the gas content of twenty transistors. The composition of the gas within these transistors was observed to vary considerably between devices from the same manufacturer as well as from one manufacturer to another. For divided gas samples analyzed by both a mass spectrograph and a gas chromatograph, data correlation between the two techniques has been good. It is believed that the main purpose of this subtask, i.e., to establish a means for analysis of the gas content within electronic parts, has been achieved. The remainder of the effort on this subtask will be devoted to gathering data for parts which are good and for parts which have failed.

Subtask 6 — Design, Materials and Process Identification of Electronic Parts (FY 1967 Funding)

The purpose of this effort is to develop methods and procedures for cataloging materials and process information on parts which are being considered for qualification testing. Information of this type will greatly aid in failure analysis and will provide a sound basis for judgements regarding the continued applicability of test data.

This effort is being pursued in two phases. In phase I, two contractors were required to develop procedures for obtaining and cataloging the desired information, to perform an exemplary effort for the 2N2222 transistor, and to prepare detailed plans for implementation of a phase II effort encompassing a variety of part types. The phase I effort has been completed and the results of this effort were used as a basis for selection of the phase II contractor. Final negotiations for the larger phase II effort are currently in progress, and a contract is expected to be executed early in the first quarter of FY 1968. During the phase II effort, approximately 80 part types will be investigated and documented in individual booklets.

Subtask 7 — Investigation of Failure Analysis Techniques for Integrated Circuits (FY 1967 Funding)

The intent of this subtask was to carry out laboratory investigations of various failure analysis techniques applicable to integrated circuits. In the course of this activity a variety of techniques were investigated. These techniques, among others, included staining of Au-Al intermetallics in bonds, staining of aluminum over p and n regions by chromate conversion, and techniques for selectively removing metalization or oxide from small areas on semiconductor devices. Notes on the application of these techniques will be used as an initial step toward compilation of a laboratory handbook of failure analysis techniques.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Klippenstein, E. T., "Design, Material, and Process Identification of Electronic Parts," SPS 37-43 Vol. IV, pp. 143 and 144, February 28, 1967.

Contractor Reports, Interim and Final

1. Final Report Transistor and Diode X-Ray Effects Test Program, The Boeing Co., Report T5-6427, April 21, 1967 (JPL Contract 951369).

2. MacDougall, R. E., and Harrington, A. L., Final Report Identifying the Design, Materials, and Assembly Processes Used to Manufacture (5) 2N2222 Motorola Transistors Submitted by JPL, Litton Systems Inc., Document AT61048B67, Revision A, March 1967 (JPL Contract DJ428114).

ANTICIPATED PUBLICATIONS

None.

STATE-OF-THE-ART TRANSISTOR EVALUATION

NASA Work Unit 186-70-01-08-55
JPL 384-00801-2-3540

W. B. Bartel

OBJECTIVE

The objective of this work unit is to perform a preliminary evaluation of those state-of-the-art transistors that become available each year and have potential spacecraft usage. The purpose of this is to be in a better position to advise the design engineers on the reliability and application of the parts before he designs them into an assembly.

The approach will be:

(1) To evaluate the design and structural features of the part.

(2) To study surface effects.

(3) To study thermal resistance.

(4) To perform a short term life test.

PROGRESS

Approximately 75% of the required equipment has been procured and delivered. This includes a clean bench, curve tracer, and IR radiometer. Burn-in chambers will be procured shortly.

To date, 40 state-of-the-art transistors have been procured and are undergoing evaluation.

The majority of the transistor types studied have met their advertised specifications, however, their characterization is quite broad with respect to actual device measurements. For example, leakage current which is specified in terms of maximum limits only can either be logarithmically distributed or bunched about a value of 1/5 to 1/3 of the limit depending upon whether the device is prechanneled or not. Characterization information on the samples purchased has been prepared. This information will be valuable in setting delta limits for screening. Two part types were found to be inferior as a result of the evaluation: ITC 2N3440 and MOT 2N3637. Four promising candidates for the Preferred Parts List have been determined: 2N4044 UCE, 2N3980 TI, 2N3954 UCE, and 2N930 NSC. Transistor Internal Structure Sheets have been prepared.

The work on the 40 transistor types is about 15% complete and will be completed during the next quarter. Evaluation of additional state-of-the-art transistors will be initiated.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

SPACECRAFT TESTING EQUIPMENT AND TECHNIQUES (186-71)

ADVANCED SOLAR SIMULATION DEVELOPMENT

NASA Work Unit 186-71-01-01-55
JPL 384-10101-2-3750
R. E. Bartera

OBJECTIVE

The goal of this work unit is to maintain solar simulation capability at a state adequate to meet the needs of thermal control and related testing of spacecraft. Continuing advancements and refinements in spacecraft design require equivalent improvement of environmental test facilities. Because of the time span required to construct or modify space simulation facilities, the technology necessary to make improvements must often be developed well in advance of any firm mission requirements. Based upon discussions with those responsible for thermal control of JPL spacecraft, we believe that there are two areas of solar simulation which need significant improvement. First, the well-known "cavity and slit problem," in which the distribution of energy (and thus local temperatures) is strongly related to the diameter of the simulated sun, requires a field angle closely approximating the true solar angle for adequate evaluation. Secondly, the gross difference between the true solar and the simulated solar spectra seriously restricts the choice of thermal control coatings for spacecraft. If the coatings do not have the same net absorptance in both spectra, test results will not predict flight temperatures directly, and adjustments must be made to the data using the analytical techniques which are sufficiently inaccurate as to require the test in the first place. Therefore a much better solar spectral simulation is strongly desired.

It is possible in the JPL Solar Simulation System to achieve both the small field angle and improved spectrum but only at the cost of drastically degrading some other parameter. The net performance of any system is a direct function of the brightness of the basic light source. Because of losses in the optical elements of practical systems, the brightness of the simulated sun will be between 10 and 20% of the brightness of the source, which means that to achieve our ultimate objectives we must have a source with 5 to 10 times the brightness of the true sun and with the proper spectrum. Our immediate goal is then to investigate ways to produce extremely bright sources.

20-kW XENON ARC LAMPS

Arc brightness in standard xenon short arc lamps can be increased by the brute force method of increasing the current in the arc. With this technique the electrodes, especially the anode, are subjected to more intense energy flux from radiation, electrons, and ions. We developed a supercooled anode which allows 20 kW lamps to operate to at least 30 kW for extended periods. We have given all the information to the lamp manufacturers, who are now modifying the JPL prototype design to make it suitable for commercial production.

VARIARC

The VARIARC is a versatile laboratory arc lamp which has been designed so that parameters which may affect arc spectrum or brightness can be easily varied and studied, most of them while the device is operating. It has been completely

assembled and was operated for the first time in May. Initial experiments with it reinforced our desire to make some studies with a low-pressure, more-easily-modified arc before mapping a detailed test program for the VARIARC. They also revealed ways in which the device could be modified for easier operation. These modifications are now complete.

LOW-PRESSURE ARC STUDIES

Since we had anticipated the need for the low-pressure studies, the equipment was on hand and very quickly assembled. Anodes were standard, water-cooled, copper-spot-welding electrodes; cathodes were slightly modified heliarc torches. These were enclosed in a pyrex cylinder and a mechanism for adjusting the arc spacing was provided. The apparatus was purged and maintained slightly above atmospheric pressure with a gas flow through the heliarc torch. A second gas flow through a tube aimed at the side of the arc was provided. Qualitative studies on electrode geometry and material, gas flows, and compositions and electrode spacings were made during June and we are now in a much stronger position to return to the VARIARC (which we will do in July). The low-pressure apparatus will be maintained operational because it is less costly to investigate electrode geometry and materials with it.

PULSED ARCS

This and following sections are not progress in the sense of hardware fabrication or experimental results but do represent real progress derived from extensive literature searches and theoretical studies which have opened exciting, novel, and promising approaches toward obtaining the order-of-magnitude increase in brightness required.

A limiting factor on the brightness of arcs is the density of ions in the plasma, which is a function of the density of atoms and the percent ionization. The latter can be increased by increasing current as stated above. While the pressure in standard arc lamps is quite high, the temperature of the plasma is also high, with the result that the density of atoms in the arc is not much different from STP conditions. It appears that when a standard arc lamp is pulsed at a slow enough rate to allow the gas between the electrodes to cool and regain its density, the average brightness over a period of time will be higher than the same lamp operated in a dc mode with the same average power. If the pulse rate can be controlled so that the shock wave generated by one pulse and reflected from a spherical wall converges on the arc gap at the same time that the next pulse is applied, further enhancement of arc brightness can be expected. Fortunately, experiments along these lines can be expeditiously performed with existing standard lamps and equipment.

NONGASEOUS ARCS

The limit of arc density is of course a solid material. This has been recognized by many investigators who require a light source with appreciable continuum energy around 500 Å and who have developed exploding wire technology. By pushing several thousand amperes through a short, thin wire in a few microseconds it is possible to achieve what amounts to a "solid" arc, that is, one which is extremely hot and dense while the light is being emitted. There are several references in the literature to repeating exploding wire devices. In one of them the "wire" was a column of liquid tin in a vacuum and the repetition rate was up to 10 times/min, limited by the rate of

charging a capacitor bank. With sufficient power available, there is no apparent reason that such devices cannot be operated at acoustic frequencies, that is, much faster than spacecraft thermal response.

JET PINCHING

One way to increase current density (and percent ionization) in an arc without increasing total current is to squeeze it with a strong magnetic field. Another way is to cool the boundary of the arc, reducing the conductivity there and forcing the current into a smaller channel as is done in capillary discharges. While we were considering ways to constrict the arc, Tamarack appeared with their jet-pinched arc, which uses a sheath of cold gas to cool the walls of the arc channel. We have ordered one with delivery scheduled for late August, and if it lives up to their claims (as we believe it will), Tamarack can be credited with an important advancement in the field. This new lamp will be thoroughly investigated.

Several years ago, Durotest Corporation experimented with the addition of small amounts of hydrogen to otherwise standard xenon compact arc lamps. Although the hydrogen diffused through the hot quartz envelope in a relatively few hours, while it remained the arc was appreciably brighter and constricted. Hydrogen modecules wandering into the arc boundary disassociated and became hydrogen ions absorbing energy and constricting the arc. Molecules were reformed on the electrode and envelope surfaces and were continuously recycled until they leaked out.

While we plan to eventually modify the Tamarack lamp to inject a sustaining gas (argon or xenon) through the cathode and a cooling gas (hydrogen or helium) around it, we have already modified a heliarc torch for similar operation. This is one more use for which the low-pressure arc apparatus will be employed during the next few months.

PUBLICATIONS DURING REPORT PERIOD

Meetings and Symposia Papers

1. Drummond, A., Laue, E., Hickey, J., and Scholes, W., "Multichannel Radiometer Measurement of Solar Irradiance," 5th Aerospace Sciences Meeting, New York, January 1967.

2. Drummond, A., Laue, E., Hickey, J., and Scholes, W., "High-Flying Aircraft Determination of the Solar Constant of Irradiation," 3rd Annual Meeting of the Solar Energy Society, Tempe, Arizona, March 1967.

ANTICIPATED PUBLICATIONS

Meetings and Symposia Papers

1. Drummond, A., and Laue, E., "On the Determination of the Solar Constant from Measurements in the Free Atmosphere and Above the Ozonosphere," to be presented at the Radiation Session of the International Association of Meteorology and Atmospheric Physics (I. U. G. G.), September 26, 1967.

2. Angstrom, A. K., and Drummond, A., "Experimental Investigations of the Rayleigh Scattering of the Atmosphere," to be presented at the Radiation Session of the International Association of Meteorology and Atmospheric Physics, September 26, 1967.

3. Drummond, A., Laue, E., Hickey, J., and Scholes, W., "The Calibration of Multichannel Radiometers for Application in Spacecraft and Space Simulation Programs," to be presented at the 18th I. A. F. Congress, September 24-30, 1967.

RADIOMETER CALIBRATION CHAMBER

NASA Work Unit 186-71-01-02-55
JPL 384-10201-2-3710

C. Martin Berdahl
Richard Rice

OBJECTIVE

The objectives of this work unit are (1) to provide calibration of radiometers used for determining the irradiance level in the JPL Solar Simulation Chambers during qualification and flight approval tests of spacecraft and (2) to correlate simulator performance with flight environment in order to provide information for spacecraft thermal design.

A small effective calibration chamber will be built in which several radiometers may be compared. Characteristics of such a chamber will be to provide a clean vacuum and highly collimated radiation necessary for the protection of the reliable calibration of radiometers and spacecraft surfaces.

The optics, light source, and the roughing pump have been procured for the chamber. Purchase orders have been let for the tank, shrouds, and diffusion pump. Design continues on some of the peripheral equipment such as the light source housing, main stand, and the collimator mounting system. Working drawings on the main stand will soon be completed. The light source reflector has been received from Ransom Labs and the 5-ton Yale Towle hoist has been received.

Plans are under way to locate the chamber in the Environmental Laboratory, JPL Building 144. As soon as the exact location is determined, drawings will be finalized.

Installation will be completed during FY 1968 on "Radiometry Instrumentation Development," NASA Work Unit 125-24-03-05-55.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

ADVANCED STUDIES (684)

ADVANCED LUNAR STUDIES (684-20)

ADVANCED LUNAR STUDIES
NASA Work Unit 684-20-00-01-55
JPL 388-2xxxx-x-xxxx
J. D. Burke

OBJECTIVES

The object of the Advanced Lunar Studies effort is to describe a consistent set of goals for post-Apollo lunar scientific exploration and to analyze the program consequences of these goals. The study during FY 1967 was jointly supported and monitored by OMSF and OSSA.

PROGRESS

The initial output of the study was a presentation to the NASA Lunar Exploration Review Conference at Goddard Space Flight Center in January 1967. The next scheduled output is to coincide with a Summer Conference on Lunar Exploration at Santa Cruz, California, in August 1967. During the last 6 mo the following items have been studied:

(1) Relationship among major lines of investigation in a lunar program dedicated to answering all questions on lunar origin and constitution.

(2) Priority measurements to be made on the moon for (a) elucidating early history of solar system and (b) giving guidance to planetary experiment plans.

(3) Instruments for lunar exploration. (Internal documents have been published.)

(4) Mission plan for early Apollo Applications lunar flights (participating in group including NASA Headquarters and Center representatives).

(5) 1967 OSSA lunar program prospectus (assistance to OSSA).

(6) Follow-on lunar orbiter missions.

(7) Scientific utility of Lunar Survey Probes.

(8) Automated mobile exploration systems.

The above studies yielded two conclusions which have led to further work. First, it was discovered that the scientific rationale demanded a class of measurements (particle-and-field experiments near the moon) for which no satisfactory spacecraft was included in the current NASA plan. Therefore, efforts were started at Goddard Space Flight Center, Manned Spacecraft Center, Ames Research Center, and JPL to work out the mission objectives and integration problems for a flight program including use of IMP/Pioneer class spacecraft as subsatellites to be ejected from orbiting Apollo-class spacecraft.

Second, it became evident that long-range surface mobility would be a requirement in future lunar programs and would also be useful in planetary exploration. Therefore, an engineering design study of automated roving vehicles was started. This study benefited from (1) previous JPL work on a Surveyor-based lunar roving vehicle (SLRV) which resulted in the delivery of prototypes by two manufacturers, (2) a current advanced-technology investigation at JPL using one SLRV as a motion-control test vehicle, and (3) work under other NASA sponsors on larger, man-carrying mobile systems.

The rover design study is continuing and is expected to be the main technical effort of the Advanced Lunar Studies team during FY 1968.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

ADVANCED PLANETARY STUDIES (684-30)

VENUS CAPSULE/LANDER STUDY

NASA Work Unit 684-30-01-10-55
JPL 388-3xxxx-x-xxxx

R. D. Bourke

Two related mission studies were conducted under this task: a 1973 Venus Capsule/Lander study and a 1970 Venus Capsule study. Each is described below.

1973 VENUS CAPSULE/LANDER STUDY

Objectives and Scope

A study of a mission to Venus in the 1973 opportunity is currently under way. The mission design uses a flyby spacecraft and a capsule that descends through the atmosphere and survives for a short time (≈20 min) on the surface. The objectives of this study are:

(1) To quantitatively determine how the Venus-only flyby/capsule mission in 1973 differs from the previously studied Venus/Mercury mission.

(2) To determine the requirements for achieving short term survival on the surface of the planet.

The study is organized in much the same way as previous efforts of this type with representatives of the various divisions supplying supporting manpower as necessary. The overall effort is approximately 10 man-years over 6 mo. The study leader is Dr. R. D. Bourke of the Systems Analysis Section.

Status

The study began in January 1967, and at the end of this reporting period is near completion; a milestone chart for the last two-thirds of the study is shown in Fig. 1.

The initial effort was on the trajectory and mission designs as these were quite different than those for the Venus/Mercury mission. Results of these are shown below.

The survival phase of the mission was treated as follows: It was felt that the second study objective could best be satisfied by finding the lowest level surviving payload that could be landed on the planet.

This decision led to the following characteristics of the capsule/lander:

(1) Descent and postlanding subsystems are identical.

(2) No soft landing or erection mechanism is provided, hence the capsule impact and resting situation are purely dictated by the environment.

(3) No surface exclusive science instruments are used although descent instruments may be used in a different mode on the surface (e.g., accelerometer as impactometer).

It should be emphasized that the postimpact science mode chosen is not necessarily representative of the way in which an actual lander would be designed. Rather, this mode was chosen because it was adequate to satisfy the second study objective and it avoided the problem of selecting a scientifically optimum complement of postlanding instruments.

Preliminary Results

The principal difference in the trajectory and mission designs between this mission and that to Venus/Mercury is that here the trajectory can be designed to optimize the capsule delivery. The principal result is to reduce capsule entry velocities to 36,400 ft/s from the previous 44,000 ft/s. This proves to be a great relief to the heat shield design. In addition, the arrival date may be chosen to allow descent on the sunlit side of the planet while maintaining direct link communications. This is impossible for the Venus/Mercury mission. The spacecraft flyby trajectory was designed to pass over some of the radar-identified features and through the earth occultation zone. The Venus/Mercury flyby was also occulted by the planet.

Direct link telecommunications were chosen for the capsule/lander because it provided adequate data rate to accomplish the mission, it did not require supporting equipment on the spacecraft, and it was better suited for unexpectedly long surface life.

Major problems associated with surviving landing are the simultaneous high pressure, high temperature, impact shock, and the degree of uncertainty on the exact nature of the environment. Candidate means for operating in this situation are still being generated.

1970 VENUS CAPSULE STUDY

Activities

During March and April 1967, the Future Projects study team supported the Lunar and Planetary Projects Office in a short study of a 1970 capsule mission to Venus. The principal contribution of the team was to provide conceptual mission and capsule designs.

Results

The following technical problem areas became apparent:

(1) Heat shield technology. It has not yet been demonstrated that heat shield materials can operate in the simultaneous heating and pressure environments of a Venus entry. From the heat shield standpoint, the mission must be considered high risk.

(2) Sterilizable silver-zinc batteries. Development must be accelerated over that being planned for Mariner Mars 1971.

(3) Sterilizable electronic components. Development status is questionable.

Major nontechnical problems were identified in the manpower/budget area, and Mariner Mars 1969 spares availability to support this mission.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

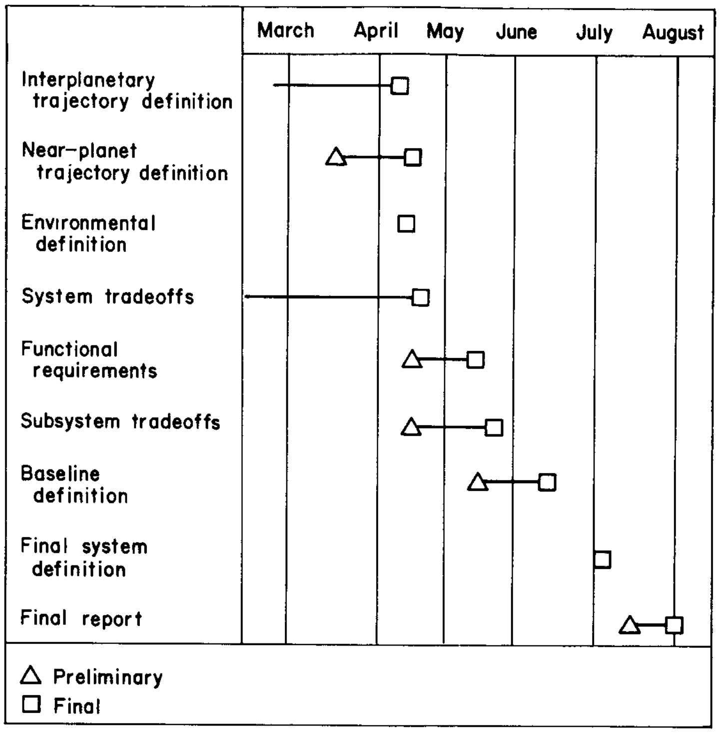

Fig. 1. 1973 Venus capsule/lander study schedule

MARS SAMPLE RETURN

NASA Work Unit 684-30-01-10-55
JPL 388-3xxxx-x-xxxx
J. Gerpheide
F. E. Rosell, Jr.

OBJECTIVE

The objective of this study is to conduct a preliminary examination of some of the problems involved in using an unmanned spacecraft system for procuring from the Martian surface a soil sample and returning the sample safely to the earth's surface.

PURPOSE OF STUDY

The purpose of the study is to provide to NASA Headquarters and JPL preliminary information upon which to base planning decisions related to further study of the problem area.

MISSION CONSTRAINTS

Major constraints imposed on the mission are:

(1) First launch opportunity is 1975.

(2) Spacecraft system is to be launched from earth with a single Saturn V launch vehicle.

(3) Spacecraft system is to use Mariner, Surveyor, LEM, Discoverer, Voyager, and other current technology bases to the maximum extent practicable.

(4) Mars atmosphere model VM-8 is to be used.

(5) Martian surface sample is to be at least one earth-lb in size, and is to be stored and transported under controlled environmental conditions on board the spacecraft.

(6) Velocity of recovery spacecraft reentering the earth's atmosphere at terminal end of mission is not to exceed 45,000 ft/s.

STUDY CONSTRAINTS

Because of time and personnel constraints, it was not possible to look at the problem in any depth, hence maximum attention was devoted to a few of the more obvious subproblem areas which would be particularly useful for a feasibility study, e.g., trajectory analysis, alternate mission profiles, propulsion requirements, conceptual configuration, etc.

CONTRACTUAL SUPPORT

Under the provisions of NASA contract NASr-65(06), assistance was provided by IIT Research Institute (IITRI) for computer-oriented data related to trajectory analyses, mission profiles, and propulsion requirements.

ACCOMPLISHMENTS DURING YEAR

Study was initiated about the end of October 1966. In November a preliminary meeting (JPL and IITRI) was held in Chicago to coordinate and firm the scope and direction of IITRI participation in the study. Initial study results identifying three possible mission modes were incorporated into briefing note form and presented (jointly with IITRI) in a briefing at NASA Headquarters in early December 1966. As a result of the briefing, the study effort was redirected, with increasing emphasis on the third mission mode. Supplemental material on the third mode was forwarded to NASA Headquarters by mid-December.

Except for residual efforts (JPL and IITRI levels of about one man each), the study effort was effectively phased out in January 1967. In February a meeting (JPL and IITRI) was held in Pasadena to coordinate and firm the preliminary summary results of the study.

In April the preliminary summary report was published; in June a draft of the JPL detailed report and a final IITRI report were published.

STUDY RESULTS

Because of the limited depth of the investigation it was not possible to provide a conclusive answer to the question of the feasibility of using unmanned spacecraft systems for returning Martian surface samples to earth. However, it does establish that the mission appears promising enough to merit in-depth study.

Mission Profile Definition

The study identifies and describes four of the more promising mission profiles, which are characterized as follows:

(1) Mode 1: <u>Descent from Mars orbit,</u> 300-day stay-time nonrendezvous direct return.

(2) Mode 2: <u>Direct Mars entry,</u> 300-day stay-time, nonrendezvous direct return.

(3) Mode 3: Descent from Mars orbit, 300-day stay-time, <u>rendezvous</u> direct return.

(4) Mode 4: Descent from Mars orbit, <u>12-day stay-time,</u> rendezvous and <u>Venus swingby</u> return.

Mission Profile Analysis

The first three of these modes were analyzed and parameters developed as follows:

(1) Complete profile from earth launch to final earth reentry and recovery was established, including time and space dimensions.

(2) Profiles were divided into sequential phases.

(3) Based upon the assumptions being used for the trajectories, ΔV components were computed for all trajectory changes involved.

(4) Propulsion stages were determined.

(5) Propellant I_{sp} values were established or assumed.

(6) Engines were selected and grossly sized as to weight on the basis of computed structure fractions.

(7) Payload fractions for descent to Mars and ascent from Mars were computed.

(8) Functional module composition in terms of subsystems was established for each phase.

(9) Weight-sizing of subsystems was accomplished for each module.

(10) Modules were integrated to establish weight-sizing of sequential phase vehicles.

(11) Vehicles were integrated to establish weight and conceptual configuration of spacecraft system.

Mission Profile Description

Table 1 provides a weight summary for the three modes. Table 2 summarizes propulsion system characteristics.

STATUS AT END OF REPORT PERIOD

The draft of the JPL detailed report has been distributed for review; comments on the draft are scheduled for submission early in July 1967.

FUTURE PLANS

Publication of the JPL detailed report in final form is anticipated during the next calendar quarter.

Future efforts related to this project are currently under review and should be finalized during the next reporting period.

Table 1. Mode weight breakdown summary[a]

Mode	Earth-Mars vehicle	Mars orbiting vehicle	Orbital maneuvering vehicle	Mars descent vehicle	Mars landing vehicle[b]	Mars take off vehicle	Pre-rendezvous vehicle	Pre-injection vehicle	Mars-earth vehicle	Earth-reentry vehicle
1	65,838	39,245	-----	36,037	14,043[c]	9,683[f]	---	1,684	580	50
2	37,903	------	-----	35,286	13,962[d]	9,683[f]	---	1,684	580	50
3	22,382	13,201	2,198	9,708	4,551[e]	3,247[g]	474	1,323	602	55

[a] Weights in earth-lb; these weights are based upon many operational feasibility assumptions which have not been verified and which require study for verification. Figure indicates effective weight at start of phase.

[b] Includes terminal descent propulsion system.

[c] Based upon descent payload fraction of 2.5:1.

[d] Based upon descent payload fraction of 3.0:1.

[e] Based upon descent payload fraction of 2.0:1.

[f] Based upon ascent payload fraction of 5.75:1.

[g] Based upon ascent payload fraction of 6.85:1.

Table 2. Propulsion system characteristics

Phase	Propellant I_{sp}, sec			Structure factor[a] (f)
	Mode 1	Mode 2	Mode 3	
1. Earth-Mars midcourse maneuvers	400	310	400	0.111
2. Injection into Mars orbit and orbit trim	400	---	400	0.111
3. Deorbit	310	---	310	0.111
4. Terminal descent	310	310	310	0.150
5. Mars launch, ascent, orbit insertion, orbit trim				
a. First stage	310	310	310	0.150
b. Second stage	310	310	310	0.200
6. Transfer of orbiting bus from high to low orbit, rendezvous and docking	---	---	400	0.111
7. Injection into Mars-earth trajectory	310	310	400	0.111
8. Mars-earth midcourse maneuvers	235	235	235	1.000

[a] Structure factor

$$f = \frac{\text{mass of propulsion system - mass of propellant}}{\text{mass of propellant}}$$

PUBLICATIONS DURING REPORT PERIOD

Contractor Reports, Interim and Final

1. Niehoff, J., Dockery, J., and Roberts, D., Preliminary Feasibility Study of Automated Mars Sample Return Missions, Technical Memorandum M-13, Astro Sciences Center, IIT Research Institute, January 1967 (draft).

2. Niehoff, J., Preliminary Payload Analysis of Automated Mars Sample Return Missions, Report ASC/IITRI M-13, Astro Sciences Center, IIT Research Institute, May 1967.

ANTICIPATED PUBLICATIONS

1. Internal JPL Documents.

VENUS FLYBY STUDY CONTRACT

NASA Work Unit 684-30-01-13-55
JPL 388-30301-2-1610
J. H. Kelley

OBJECTIVE

The objective of this task is to perform a study of a 1972 flyby and entry mission for Venus with application to the 1973 opportunity. The mission is intended to include a modified Mariner 1969 spacecraft with an atmospheric entry capsule that is not designed to survive impact.

EFFORTS TO DATE

Proposals from several contenders were received on January 31 and were evaluated during February. The top contenders were visited and interviewed. Avco was selected as the mission study contractor, with Northrop as a subcontractor for the spacecraft aspects of the study. The contract was started on May 25 and is scheduled for a completion of technical efforts on November 25. There will be an interim review at JPL in early September and a final presentation at JPL in early December. The final report is scheduled for publication in January 1968. A work plan review by JPL's study team and representatives of NASA Headquarters and Ames was conducted at Avco on June 8 and 9.

An addendum to the contract to increase the scope in the areas of aerothermodynamics and heat shield technology has been negotiated and should be ready to start in early July. The specific purpose of the addendum is to assess the state of the art of heat shield technology as pertains to a Venus 1972 mission.

The contract is basically on schedule, and it is too early to draw conclusions from the study effort.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

Part B

Physics and Astronomy

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PHYSICS AND ASTRONOMY (188)

MAGNETODYNAMICS IN SPACE (188-36)

MAGNETIC PHENOMENA

NASA Work Unit 188-36-01-01-55
JPL 385-60101-2-3280
E. J. Smith

OBJECTIVE

The objectives of this work unit are: (1) to investigate naturally occurring extremely low-frequency (ELF) (3 to 3000 Hz) magnetic field variations that propagate through the ionosphere, to study their origin, modes of propagation, and association with solar-terrestrial phenomena; and (2) to utilize techniques for the detection and analysis of signals observed at the earth's surface which may be applicable to experiments on satellites and space probes.

Simultaneous measurements are made above and below the ionosphere utilizing a satellite and a ground based observatory. OGO-2 contains, and OGOs D and F will contain, search coil magnetometer experiments measuring magnetic field variations from 1 to 1000 Hz. JPL personnel are operating a remote field site where naturally occurring magnetic (and electric) field variations are detected and recorded on magnetic tape.

DATA ACQUISITION

A low-noise ultra-high input impedance preamplifier for use with the electric field detector has been designed and built and is now undergoing evaluation at the field site. Very little useful OGO-2 data have been obtained from Stanford University to correlate with signals seen at the ground station, chiefly due to low telemetry signal strength associated with an improper OGO-2 orientation. Consequently, the NASA tracking station at WTR was contacted and arrangements were made to have it record OGO-2 special purpose telemetry data while signals were being simultaneously recorded at the field site. These data are now undergoing evaluation.

DATA ANALYSIS

There have been two major improvements in the data analysis system located at JPL: (1) a universal time code translator has been received and integrated into the system, and (2) a real time spectrum analyzer and storage oscilloscope are being used to permit continuous monitoring of the spectral content of both observatory and satellite data.

The analysis of observatory and satellite data has continued. The gliding tones mentioned in previous reports have been positively identified as due to helicopters that occasionally fly over the field site from the Naval Ordnance Test Station near Morris Dam. The search for nonsferics in the ground station data is continuing.

STATUS

The field site is being improved in preparation for the impending OGO-D launch. The search for nonsferic signals in the ground station data is continuing. Recent OGO-2 data, obtained this time over the western part of the continent by a

NASA tracking station, are being studied for simultaneous signals seen at the earth's surface.

GOALS DURING NEXT PERIOD

The goals for FY 1968 are as follows:

(1) To acquire simultaneous surface and OGO-D data. Hopefully, OGO-D will have a significantly lower level of spacecraft generated interference than OGO-2.

(2) To continue the search for legitimate nonsferic signals in the surface data (i. e., signals that originate within, or above, the ionosphere). This investigation should be greatly facilitated by the use of a real time spectrum analyzer and motion picture camera.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

SOLAR PHYSICS (188-38)

PHOTOHELIOGRAPH STUDY FOR THE APOLLO TELESCOPE MOUNT

NASA Work Unit 188-38-01-50-55
JPL 385-80101-2-3230
J. D. Allen

OBJECTIVE

The objective of this task is to study the feasibility of conducting a flight program with a moderate-size solar telescope on the Apollo Telescope Mount (ATM) to obtain high-resolution motion pictures of the sun in white light, near-UV, and narrow-band Hα. A set of functional requirement documents will be written ranging from general mission and equipment requirements to design requirements for individual subsystems. An implementation plan will also be written detailing the work plan, resource and facility requirements, and performance schedule.

PROGRESS

A flight telescope system has been optimized for the study. As illustrated by the sketch (Fig. 1), it consists of a Cassegrainian telescope, three film cameras, one TV camera, and a display and control console that would be mounted in the LM/ATM, to be operated by the crew. One film camera would be used for each of the three spectral bands, namely, white light, near-UV and Hα. Simultaneous recording of the images is possible by this arrangement. Another arrangement of cameras (Fig. 2) was investigated as an improvement in the accessibility that the crew would require for adjustments or for removal and replacement of film cassettes (Fig. 3).

An analysis of the optics has been accomplished which shows that a Cassegrainian system can be used within the space constraints of the ATM and which will provide the desired diffraction limited image. Design parameters for the optics have been calculated. The results of the analysis have been checked by a computerized ray tracing program which shows that the aberrations of the system are well within the requirements.

An analysis of the temperature distribution and distortion of a quartz primary mirror was conducted, based on a JPL computer program ELAS. The significance of the results is being interpreted. The analysis will be extended to determine the possibilities of employing experimental techniques in evaluating the suitability of other materials for the mirrors. Should active thermal control be required, a number of possible methods is being considered for more detailed study.

An evaluation of possible structural support of the optics to maintain the qualities of a diffraction limited condition shows that an integral assembly employing low-expansion materials is best. Close ATM control of the thermal environment for the telescope is desired. Preliminary results indicate that thermal provisions in the telescope may also be necessary.

Approximations of the weights, centers of gravity, and moments of inertia of the telescope system were determined for the reference axes of the ATM.

A detailed progress report of the activity to date is being published. The contents will include the following subjects:

(1) Scientific objectives of the experiment.

(2) Mission description of the telescope.

(3) Telescope description of the subsystems.

(4) Optics requirements and design.

(5) Analysis of materials applicable to the mirrors and telescope structure.

(6) Analysis of the thermal distribution and behavior of the primary and secondary mirrors.

(7) Possible methods of active thermal control of the mirrors.

(8) Concepts of the camera system.

(9) The requirements of telescope alignment in flight.

(10) Concepts of reliability and an approach to the testing of the telescope system.

(11) The environmental requirements in terms of the mission profile.

During the next reporting period, the study will concentrate on the thermal problem and evaluation of candidate mirror materials in a phase to establish design criteria for the prototype telescope. Additional computerized ray tracing of the optics of the telescope will be conducted to determine aberration patterns for various misalignment conditions, in an attempt to establish optics constraints on the telescope. Methods of alignment of the telescope in flight will be studied to evaluate preflight alignment and in-flight realignment procedures.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

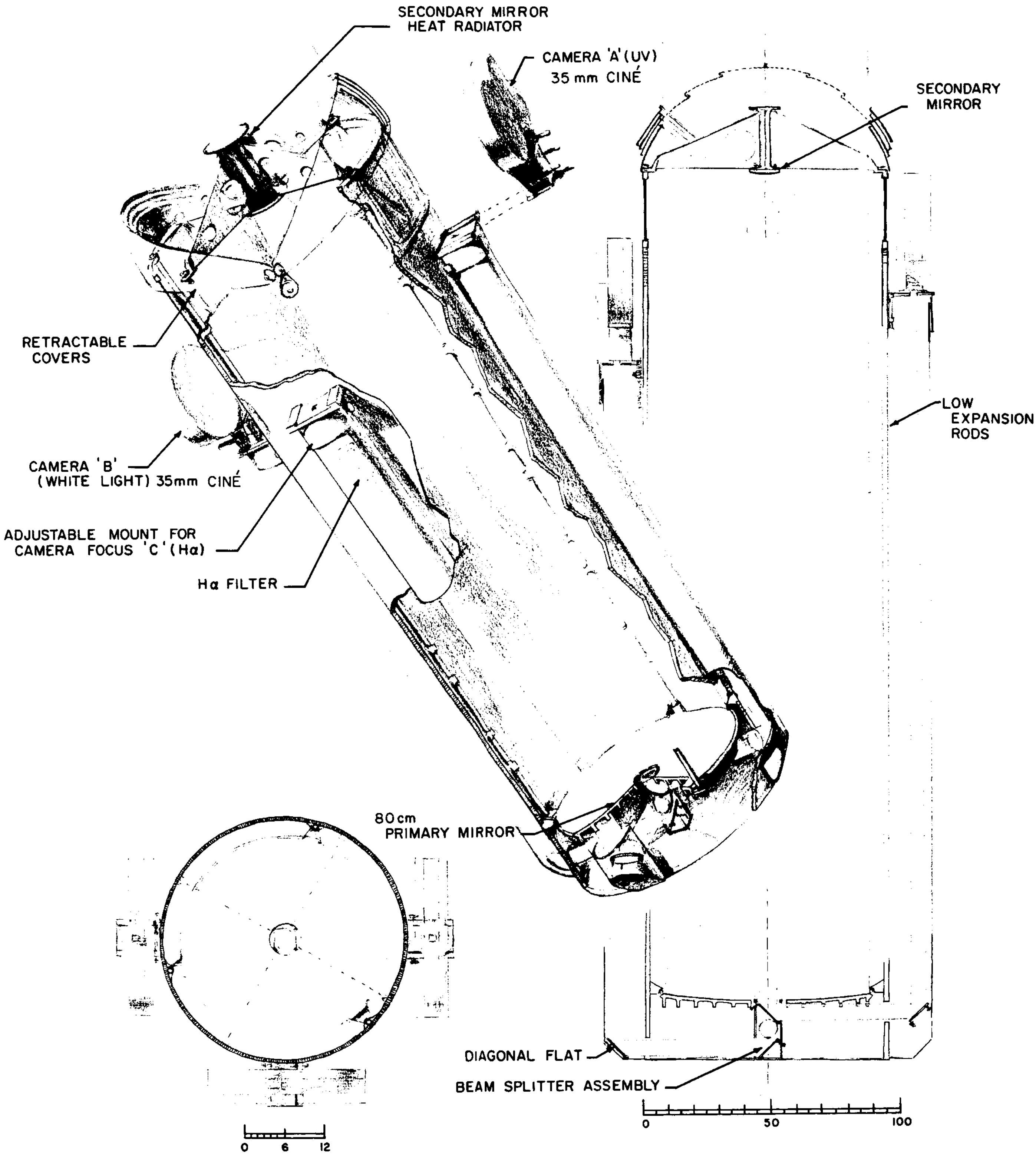

Fig. 1. Solar telescope

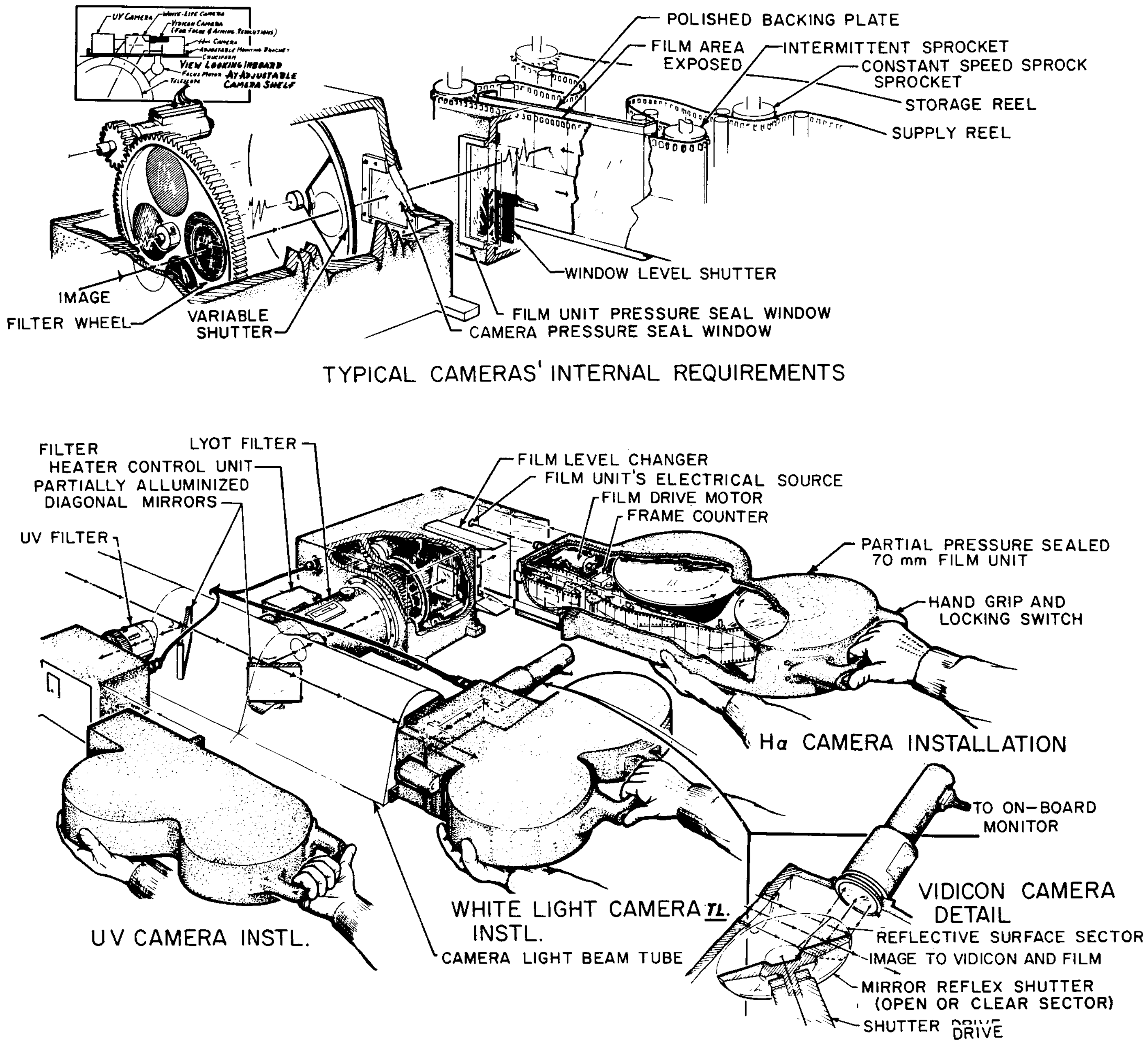

Fig. 2. Saturn/Apollo ATM telescope camera reels accessibility and mechanisms

ELECTRONIC COMPONENT LONG-LIFE STUDIES

NASA Work Unit 186-70-01-05-55
JPL 384-00501-2-3540

L. W. Wright

OBJECTIVES

The objectives of this work unit are to examine the behavior patterns of electronic parts during life test and investigate methods for the prediction of part parameter values and part failure rates after as much as 7500 h of operation. These predictions shall be based on early life characteristics. A secondary objective is to investigate part failure modes as a function of time and stress.

ACTIVITIES DURING REPORT PERIOD

Subtask 6 — Diode Comparative Screening Test (FY 1965 Funding)

The purpose of this effort was to investigate the effects of nine separate types of electrical/thermal screening processes on the subsequent behavior of two types of diodes during life test. JPL Contract 951367 was awarded to Preston Scientific of Anaheim, California to perform this test program.

All testing covered by JPL Contract 951367 has been completed and the contractor's report has been received. For both the Fairchild FD600 and the TRW 1N649, the ac-cycled and ac-accelerated stresses appeared to be excessively stringent, i.e., these stresses seemed to induce failure or excessive drift later in life. For the FD600 the most effective screen was reverse bias, while for the 1N649 screening with I_0 = 280 mA at 60 Hz with V_R = 600 Vdc appeared to be most effective. The 1N649, however, was less stable than the FD600 throughout the entire test. This is attributed primarily to the fact that the FD600 is a planar diffused device. These results indicate that a standard screen will not necessarily be equally effective for devices fabricated by different techniques.

Subtask 7 — Accelerated Life Test Program for NPN Planar Transistors (FY 1966 and 1967 Funding)

This effort is intended to explore the utility of data from both step-stress and high-constant-stress tests in predicting the behavior of 2N2222 transistors during life when operated under nominal use conditions. The accelerating stress is applied power to produce specific values of junction temperature.

This test program covered by JPL Contract 950541 is progressing satisfactorily. Work completed to date includes manufacture and inspection of the necessary test samples, screening of the test samples, thermal impedance measurements, fabrication of all life test circuits, and completion of 750 h of testing on the rated life test group. Some equipment problems were encountered during the thermal impedance measurements. At the start of life test, transistor oscillation presented a problem but was eliminated through the use of ferrite beads. During the first quarter of FY 1968, all data analysis programs will be debugged, life testing of all groups will be initiated, and testing of some of the shorter step stress test groups will be completed.

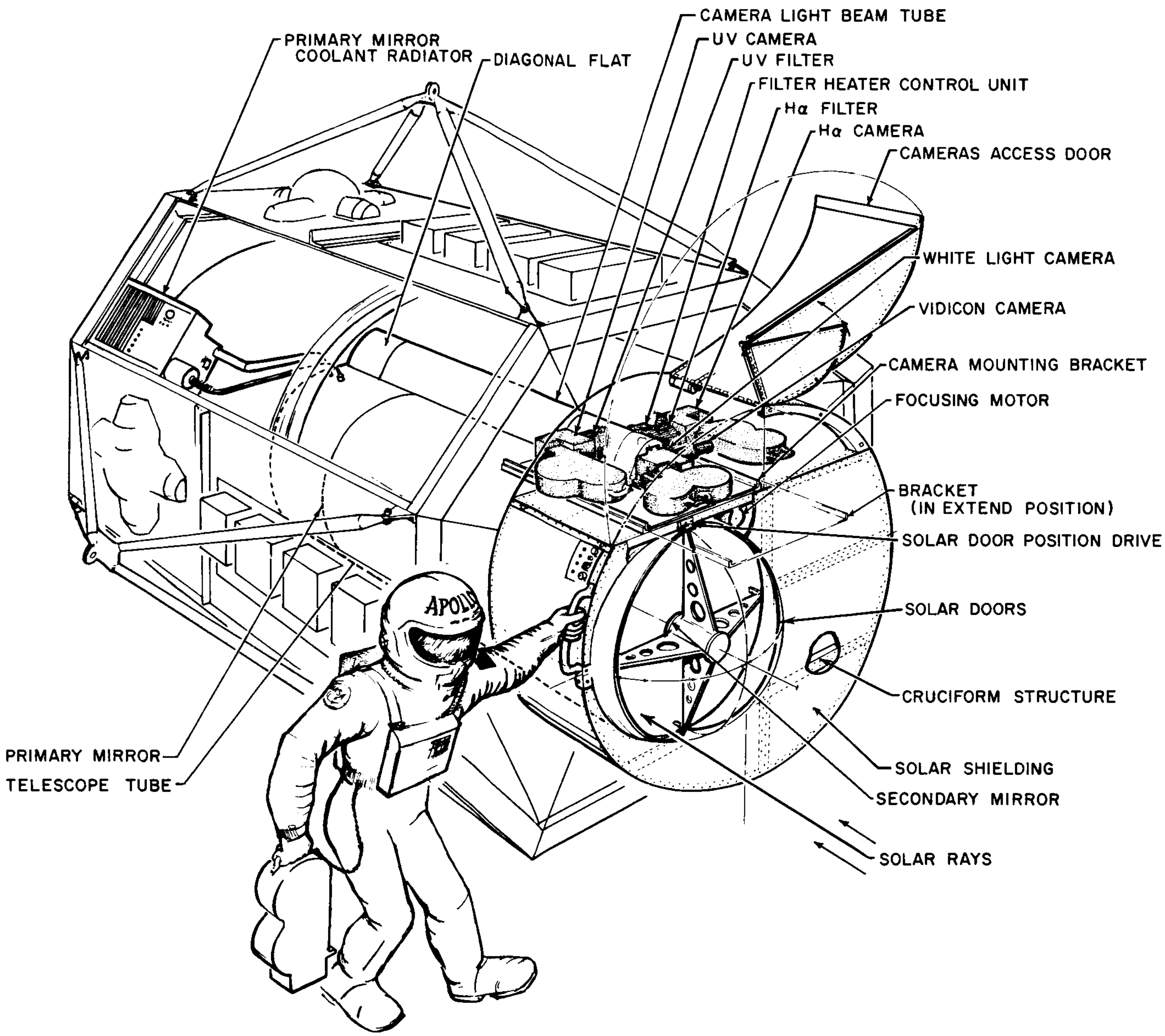

Fig. 3. Saturn/Apollo ATM telescope and secondary equipment installation

ENERGETIC PARTICLES (188-46)

RADIATION EXPERIMENTS
NASA Work Unit 188-46-01-01-55
JPL 385-60301-2-3280
W. S. McDonald

OBJECTIVE

The objective of this work unit is to develop new experimental concepts and techniques for the study of high-energy radiation. Current interest centers around a spark chamber designed for the study of energetic protons, alpha particles, and neutrons associated with galactic cosmic rays and solar flare radiation phenomena.

The primary objective of the spark chamber program for FY 1967 was to prepare for and conduct balloon experiments using progressive developmental models of spark chamber systems. The first chamber, sensitive to high-energy charged particles, was to be tested in balloon flights at low and high magnetic latitudes. The second chamber, which is specifically designed to detect energetic neutrons, was to be tested in the laboratory during FY 1967 to investigate its feasibility.

PROGRESS

Balloon flights from Palestine and Ft. Churchill were successfully completed (on July 10 and August 7, respectively) as reported in the last semiannual report. The effort during this report period has been devoted to data reduction and proving the feasibility of the neutron detection scheme.

Reduction of the balloon flight data has shown that the instrument functioned well. When completely analyzed, these data will give the angular and energy distributions of protons above 60 MeV and alpha particles above 240 MeV in the primary cosmic rays and the cosmic ray albedo. Difficulties in computer programming and program debugging have been resolved, and a comprehensive report on these flights is in preparation.

Work has also been proceeding on a laboratory feasibility study of a spark chamber suitable for detecting the direction and energy of atmospheric and solar neutrons from a high-altitude balloon. The proposed method of neutron detection is based on the fact that a neutron reacting with He^3 produces a recoil proton and triton (see Fig. 1). Our tests have shown that spark chambers will operate satisfactorily using helium as a filling gas. A schematic diagram of the proposed balloon flight neutron chamber is shown in Fig. 2. When a neutron with energy greater than 3 MeV reacts with an He^3 nucleus inside the volume enclosed by the inside cubical chamber, the recoil proton and triton will each pass through the spark gaps of the inside and outside chambers and be detected by scintillators within the chamber. The scintillator pulse height analysis will give the energies of the recoil particles. From the spark chamber data the total angle ($\theta + \phi$ in Fig. 1) between the particles can be determined. A preliminary analysis of experiments conducted on a laboratory neutron chamber, using a neutron source, gives results agreeing with theory.

Meanwhile, a breadboard of a new digital readout system for spark chambers utilizing magnetostrictive delay lines, rather than the present magnetic cores, has

been constructed and tested. This magnetostrictive system operates very well and is considerably simpler than a magnetic core system. It is also much less susceptible to high-voltage breakdown problems than a core system when used to read out the high-voltage planes of the spark chamber gaps. For these reasons it possesses important advantages over a core system for a digital flight instrument. In addition, important improvements in technique have also been developed for spark chamber scintillator light pipe systems.

It has been decided that this task will not be continued into FY 1968. Therefore, the original plans to begin construction of a neutron balloon flight chamber for launching in the fall of 1967 have been abandoned. Work on this task will be closed out at the end of FY 1967 with the writing of comprehensive reports on the Palestine and Ft. Churchill flight instrumentation and results, together with reports on the results from the laboratory neutron chamber and a description of the magnetostrictive readout system.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

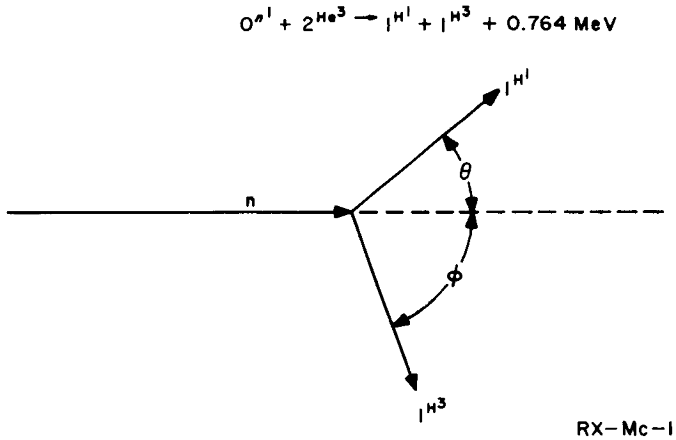

Fig. 1. Basic reaction for neutron detection

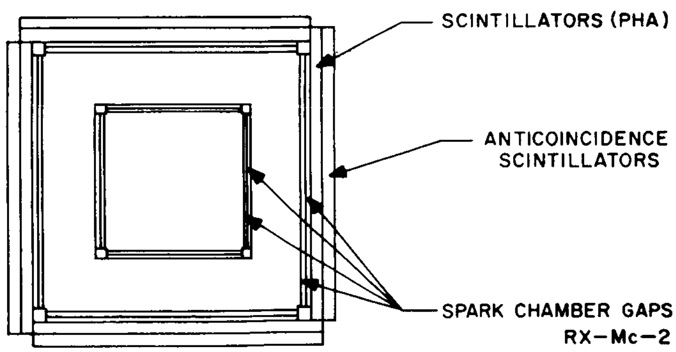

Fig. 2. Schematic of neutron spark chamber

DATA ANALYSIS (385)

FIELDS AND PARTICLES DATA (385-48)

ANALYSIS OF FIELDS AND PARTICLES DATA

NASA Work Unit 385-48-01-01-55
JPL 375-80101-2-3280
M. Neugebauer

OBJECTIVE

The objective of this work unit is to conduct scientific analysis of the fields and particles data obtained from Mariner II and to prepare for similar analysis of data from OGO and ALSEP experiments.

MARINER II DATA ANALYSIS

Two data tapes (one of raw data and the other of data reduced according to a radial flow, isotropic velocity model of the solar wind) were prepared, together with descriptive documentation for the National Space Science Data Center.

The Mariner II plasma and magnetometer data show evidence of low-frequency hydromagnetic waves. The presence of such waves has been essentially verified. owever, the Mariner II measurements may not be sufficient for a quantitative analysis of the modes (one Alfvén and two magnetosonic). Only one component of the ion velocity was recorded, and density was determined under the assumption that the velocity was radially away from the sun. Therefore, ambiguities exist in the computer solutions of the hydromagnetic wave equations, and at present it is not certain that these ambiguities can be resolved. If further attempts prove unsuccessful, the existing analysis and computer programs will be revised to accommodate the Mariner IV plasma data. The problem of resolution of the modes was discussed with (1) Dr. L. Davis, Jr., California Institute of Technology, (2) Dr. Paul Coleman, University of California at Los Angeles, and (3) Dr. R. May, presently at California Institute of Technology.

The detailed structure of M-region streams was studied in an attempt to identify their source on the sun. It was determined that the observed patterns of velocity vs azimuth angle are often inconsistent with a steady-state flow of a frozen-field fluid. An outward extrapolation of the M-region structures to the orbit of Jupiter is being performed in hopes of finding correlations with Jovian radio emission. This investigation may or may not prove fruitful.

EGO AND ALSEP ANALYSIS

Computer programs are being written which combine the response functions of the JPL OGO-E and ALSEP plasma spectrometers with various models of the solar wind so that different types of plasma distributions can be recognized when and if they are encountered. The rate of progress on these projects is consistent with the respective launch dates.

PUBLICATIONS DURING REPORT PERIOD

Papers Presented at Meetings and Symposia

1. Unti, T., "Examples of Low Frequency Hydromagnetic Waves in the Solar Wind," presented at annual American Geophysical Union Meeting, Washington, D. C., April 17-20, 1967.

Open Literature

1. Neugebauer, M., and Snyder, C. W., "Mariner 2 Observations of the Solar Wind 2. Relation of Plasma Properties to the Magnetic Field," J. Geophys. Res. 72, 1823, 1967.

2. Neugebauer, M., "Mariner-2 Observations of the Solar Wind," Plasmas in Space and in the Laboratory, ESRO SP-20, pp. 171-179, 1967.

JPL SPS Contributions

1. Unti, T. W., and Neugebauer, M., "Analysis of Mariner 2 Data for Alfvén Waves," SPS 37-41, Vol. IV, p. 181, October 31, 1966.

ANTICIPATED PUBLICATIONS

None.

BIOSCIENCE (189)

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Part C
Bioscience

EXOBIOLOGY (189-55)

GROWTH AND PHOTOSYNTHESIS

NASA Work Unit 189-55-02-01-55
JPL 386-51101-2-3260

G. L. Hobby

OBJECTIVE

The objective of this task is to develop a life detection experiment to test Martian surface matter for the presence of light-dependent fixation of atmospheric gases, especially carbon dioxide.

STUDIES OF CARBON DIOXIDE FIXATION CAPACITY OF FRESH SOILS

The results of tests to determine the CO_2 fixation of several desert soils was reported in the previous semiannual report (JPL TM 33-322, Vol. I). These soils had been stored for from 2 1/2 to 3 1/2 yr under air-dried conditions. CO_2 assimilation by some of these soils could not be detected. Questions arise as to whether this is due to the loss of viability of CO_2-fixing organisms in these stored soils or whether the soils were originally deficient in photosynthetic and other microorganisms which fix carbon dioxide.

A variety of fresh soils, including two obtained from Cameron's Antarctic collection (500 and 537), was tested by the methods developed previously. The collection sites included those where there were relatively rich soils and sites that were devoid of macroscopically visible forms. All soils exhibited significant dark as well as photosynthetic carbon-dioxide assimilation. Standard culture procedures indicated that the Antarctic soils contained either very few viable photosynthetic organisms, or that the standard culture techniques used to determine their presence are not adequate for stimulating their growth. In one set of soil samples which was collected in an area of deep shade no photosynthesis was observed, but significant CO_2 uptake occurred during incubation in the dark.

Further tests are to be made on soils collected at a single site to compare samples stored for 3 or 4 yr under air-dried conditions, stored in a frozen state, and recently collected from the same site.

MEASUREMENT OF CARBON-DIOXIDE FIXATION IN SOIL *IN SITU*

One approach which was considered for performing a life detection experiment by detecting carbon dioxide assimilation was to isolate an area of the soil surface by inverting a transparent chamber over it. Incubation, after radioactive carbon dioxide is introduced into the chamber, should result in a detectable accumulation of radioactivity in the soil. The results of these experiments suggest that the method is not satisfactory. Significant CO_2 uptake was obtained but the accumulated radioactivity in the soil fell far below the activity of fresh samples of equivalent weight collected at the same site and incubated in the laboratory. The problem is that $^{14}CO_2$ injected into the chambers at the beginning of incubation rapidly diffuses into the soil and leaks through the contact surfaces between chamber and soil. Thus, the $^{14}CO_2$ concentration in the chamber decreases too rapidly to permit efficient incorporation

by the microorganisms present in the soil. No further investigation of this method is planned.

VOLATILIZATION OF PHOTOSYNTHETIC PRODUCTS BY ACIDIFICATION

The method for eliminating residual radioactivity due to adsorption or carbonate formation that may occur in soil samples is to acidify them after incubation. It was previously reported that some of the biologically accumulated radioactivity was volatilized when these samples were treated with strong acids and heated to dryness. Attempts to identify volatile products arising from acidification have been negative. Further efforts to identify these products will not be pursued at this time because other approaches to removing nonbiological CO_2 accumulations are being considered.

RESULTS OF PYROLYSIS AND COMBUSTION OF SAMPLES

Preliminary tests were made to determine the feasibility of detecting, by mass spectroscopy, ^{13}C labelled substrates produced by soil organisms during photosynthesis. Algae were grown in culture media containing $^{13}CO_2$. After incubation, the culture suspension was centrifuged and the cell fraction obtained was lyophilized. Lyophilized samples were dry-combusted, and the carbon dioxide that was produced was determined by a mass spectrometer. The fraction of ^{13}C recovered from this combustion agreed closely with the calculated values for ^{13}C which should have been incorporated into cellular material during incubation. These results indicate that the combustion method used is promising for detecting biological carbon fixation by mass spectrometry.

Similar lyophilized samples were pyrolyzed and the volatile pyrolysis products analyzed on a combination gas chromatography-mass spectrometer system. The presence of ^{13}C in volatile organic pyrolysis products was detected in the mass spectrogram.

The results of preliminary experiments in which incubated samples are combusted or pyrolyzed have suggested approaches other than determining the radioactivity of soil samples by planchet counting, as presently performed. Soil samples that have been incubated in $^{14}CO_2$ can be pyrolyzed. Biological substrates that are synthesized during incubation are labelled with ^{14}C. Upon pyrolyzing these samples, $^{14}CO_2$, $^{12}CO_2$, H_2O, and C-14 labelled organic pyrolysis products would be produced. The volatile radioactive products can be separated by gas chromatography and analyzed by internal flow gas radiation detectors with very high sensitivity. The advantage of this method is that, if proper pyrolysis conditions are obtained, the detection of radioactive organic pyrolysis products verifies that biological assimilation of CO_2 has occurred.

For the next period the main problem to be investigated is determining the optimum conditions for pyrolyzing samples in order to obtain pyrolysis products that are compatible with detection by an internal gas counter.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

FLUOROMETRY AND BIOSPECTROSCOPY

NASA Work Unit 189-55-02-02-55
JPL 386-50201-2-3260

J. H. Rho
P. J. Geiger
J. P. Hardy

OBJECTIVE

The long-range objective of this task is to develop techniques for detecting life and its associated organic chemistry for the Voyager program. Currently, the objective is to develop fluorometric assays for biological pigments and nucleic acids, and IR, UV, and visible spectroscopic assays for all major biological compounds in soils.

FLUOROMETRY

Chemical methods for the quantitative determination of soil microorganisms have been partially developed. Quantitative estimation of photosynthetic bacteria and algae in soil samples have been made by their chlorophyll content. Soil samples were extracted in 80% methanol at 100°C for 3 min along with known numbers of algae or photosynthetic bacteria and the amount of extracted chlorophyll determined by its fluorescence intensity. By comparing the average chlorophyll content of the reference organisms with the amount of chlorophyll extracted from soils, the number of photosynthetic microorganisms in the soil samples was calculated.

Reasonably accurate estimation of the total number of cells in any soil sample can be made by determining the quantity of nucleic acids present. For the determination of the amount of RNA in soil, samples were first washed with 0.3N trichloroacetic acid. They were then briefly washed with cold (0 to 2°C) 0.3N KOH to remove the bulk of humic acid. The hydrolysis of the washed soil samples in 0.1N KOH at 100°C for 10 min yielded a highly fluorescent product which emits maximally at 390 μ in an acid medium. The number of soil organisms was estimated by comparing the fluorescence intensity of this extract with that obtained from extracts of known numbers of organisms. This method is quite satisfactory for the desert sandy soil in which humic acid content is negligible. Soil containing a large amount of humic acid, however, interferes with this method, for humic acid is also extracted in basic solution. Removal of humic acid either by precipitation with acid or by ion exchange column technique is desirable to get better accuracy.

The amount of DNA present in any soil sample can be determined by the method involving the synthesis of quinaldine, whereby aldehydes of the type R-CH_2-CHO yield strongly fluorescent products when allowed to react with 3, 5-diamino benzoic acid dihydrochloride (DABA) under prolonged heating in concentrated mineral acids. The samples were first washed with 0.1N alcoholic potassium acetate and ethanol to remove any lipids materials present. The lipid-free samples were then reacted with 2M DABA in capped tubes at 60°C for 20 min. Fluorescence of the extract was measured at 510 μ with the maximum excitation at 410 μ. By comparing the fluorescence to known standards, the DNA content of the soil samples was determined. Presence of a relatively large amount of humic acid in the soil sample did not interfere. This method has been successfully applied to a wide variety of natural soil

samples such as humic soils, sandy soils, and arid Atacama desert soils to estimate the soil microorganisms.

An attempt was made to use the chlorophyll fluorescence activation spectrum to obtain a total absorption spectrum of the associated photopigments in photosynthetic organisms. By use of a linear energy fluorometer, the activation spectrum of purified chlorophyll a was found to be identical with its absorption spectrum. The activation spectrum of crude 80% methanol extract of Chlorella pyrenoidosa also corresponded with its absorption spectrum. By use of this technique the absorption properties of coordinated pigments can be determined with much greater sensitivity than by simple absorption spectroscopy.

Future Activities

Fluorescence and phosphorescence methods will be developed for the qualitative and quantitative determination of pyran, pyrrole, and polyene pigments. The methods for determining the phosphorescence and fluorescence properties of nucleic acids and their derivatives will be refined with respect to temperature, media, hydrolysis conditions, and the presence of interfering substances in soil.

IR Spectroscopy

Infrared spectroscopy has, within the past few years, become feasible for life detection with remote instrumentation by the advent of frustrated multiple internal reflection (FMIR) optics. This permits increased sensitivity and simplifies handling solid and liquid samples. It also permits examination of intact molecules with minimal or no chemical alterations of structure.

Groups of biological compounds significant for life detection are: lipids, sugars and polysaccharides, peptides, proteins and amino acids, amino sugars and amino polysaccharides, organic phosphates, and pigments and chlorophylls. These groups have been readily observed by FMIR infrared spectroscopy after extraction from soil and purification by relatively simple procedures.

The spectrum of lipids extracted with a chloroform/methanol solution clearly showed frequencies due to C-H and to C=0, present, perhaps, in fatty esters. Sugars and polysaccharides in an acetone precipitate from hot water extract were indicated by their strong polyol bands. Proteins and peptides hydrolyzed with 1N HCl at 100° have been demonstrated along with free amino acids by the characteristic band structure of their hydrochlorides observed after desalting with Dowex 50 resin. This was accomplished by an improved, one-step desalting procedure using the resin in the ammonium form and eluting with 0.05M NH_4OH after placing the hydrolyzate directly on the column. In addition, a spectrum taken of the sodium salts of these amino acids confirms the presence of amino and carboxyl groups by disappearance of the $-NH_3^+$ and $-COOH$ frequencies and appearance of the $-COO^-$. Two dimensional TLC of these amino acids has confirmed the presence of many of those observed in soil hydrolyzates by other workers. Amino sugars were detected in the above acid hydrolyzates and have also been examined as the amino sugar hydrochlorides after hydrolysis with concentrated HCl at room temperature and from a 4N HCl hydrolyzates. Glucose amine and galactoseamine were obtained in extremely pure form by selectively eliminating salts and amino acids with 3 columns

(in series) of Dowex 50 ion exchange resins. Frequencies of the polyol and NH_3 + groupings are important here; the spectrum obtained was identical with a 1:1 mixture of authentic glucoseaminehydrochloride and galactoseaminehydrochloride. TLC also demonstrated their presence unequivocably.

Organic phosphates obtained by alkaline hydrolysis with 0.1N NaOH at room temperature followed by precipitation at pH 3 were demonstrated by the characteristic P-O-C band.

Chlorophylls have been examined after extraction of Chlorella pyrenoidosa and Rhodospirillum rubrum with acetone, and the bands obtained correlate extremely well with those in the literature. Spectra of these same intact organisms show the expected amide (protein) and C-H frequencies and, in addition, a band that has been attributed to polyol compounds and phosphates.

Humic acid has a broad and uninformative spectrum; however, when dissolved in NaOH, the - COO^- are clearly seen. Finely ground, native soil (5% organic matter) showed only a broad silicate band when examined, since without any preparation, the organic matter is too dilute to be seen readily.

Lignoproteins and purines and pyrimidines are currently being investigated also, but the methods are not yet well enough developed to obtain good IR spectra.

Excellent spectra of peptides have been obtained after partial hydrolysis at 35° with acetic acid - 1N HCl mixtures. This was followed by desalting with Dowex 2 resin and a final removal of (presumably) chelated metal ions with Chelox 100 resin. The spectrum was virtually identical to that of partially hydrolyzed bovine serum albumin which contains primarily dipeptides. The amide I and II bands are important features here.

Almost all of the above spectra were taken after samples had been dried on the surface of a 50x20x-2 mm germanium internal reflection crystal. In some cases inorganic materials must be removed to obtain the best spectra. In all cases the simplicity of the extraction and purification methods consistent with specificity had been emphasized.

Future Work

Further study will be made of infrared spectra of aqueous acid and base, as well as organic solvent extracts of different kinds of soils. This will confirm the power and usefulness of infrared methods for determining the presence of the important groups of biological and related compounds. Other organic and inorganic compounds will also be included as necessary.

Studies of the extraction and purification procedures themselves will be continued to obtain the sharpest, most specific infrared spectra possible, consistent with simplicity of the procedures. Both wet and dry preparations and techniques will be included.

An attempt to optimize the sensitivity of the FMIR method with available combinations of crystal types and sample preparation methods will be made. Commercial grating spectrophotometers will be used.

An attempt to determine the usefulness of infrared spectroscopy for obtaining information on life-related compounds prepared by gas chromatographic methods will be made. This will help point out how spectroscopic methods and GC-MS can be coordinated to obtain complementary information for life detection.

Most organic compounds of biological interest are nonvolatile solids. A complex mixture of these compounds accompanied by varying amounts of inorganic salts are rather difficult to separate. Volatile compounds are generally much easier to separate from one another, particularly when using gas chromatography. It would be advantageous, then, if stable, volatile derivatives of the compounds of interest could be made. Indeed, the method is available. As with silicon polymers, which are stable at relatively high temperatures, trimethylsilyl derivatives, which are volatile and thermally stable, can be made from a wide variety of compounds. The conditions under which the derivatives are formed are mild, and little or no alteration of the parent compound has been observed. The following is a list of classes of compounds of which trimethylsilyl derivatives have been made and characterized by gas chromatography:

(1) Amino acids.

(2) Peptides.

(3) Purines.

(4) Pyrimidines.

(5) Nucleosides.

(6) Nucleotides.

(7) Sugars.

(8) Oligosaccharides (tetramers!).

(9) Amino sugars.

(10) Steroids and lipids.

Trimethylsilyl derivatives are particularly easy to make, and the technique is amenable to automation. A solid or liquid of which a derivative is to be made is mixed with an aprotic solvent such as pyridine, followed by the trimethylsilyating reagent, e.g., N', O' bis-trimethylsilyl acetamide. The solution is warmed for a short period of time (50 to 60°C for 10 to 30 min) and a small sample is removed to be analyzed by gas chromatography. The derivatives may be analyzed by any or several of the methods listed: mass spectrometer, flame ionization, and infrared or ultraviolet/visible spectroscopy.

Although it is possisble to make trimethylsilyl derivatives of pure compounds or mixtures of pure compounds, it is necessary to show that the volatile derivatives can be made and analyzed when the compounds have been extracted from soil. To this end, a simple acid hydrolysis of soil was made under conditions which hydrolyze proteins and peptides to amino acids. The hydrolysate was filtered through an ion-exchange resin to remove some of the salts and mineral contaminates. The filtrate was evaporated and derivatized. The gas chromatographic spectrum indicated the presence of several amino acids and amino sugars.

The best methods for analyzing the derivatives after separation by gas chromatography are being investigated. Mass spectrometric analysis is a logical consideration as well as various spectroscopic techniques. Of interest is the possibility of analyzing the trimethylsilyl derivatives of aromatic compounds by ultraviolet absorption spectroscopy. Since aromatic compounds in the gas phase display unique absorption spectra, it might be possible to identify various compounds directly in the effluent stream from a gas chromatograph.

Preliminary studies of the mechanism of the trimethysilylation reaction are continuing in order to establish the optimum conditions under which the trimethylsilyl derivatives may be formed.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

BIOSCIENCE EXPERIMENT DEVELOPMENT

NASA Work Unit 189-55-02-03-55
JPL 386-51301-2-3260

G. A. Soffen

OBJECTIVE

This work is directed towards developing methods for life detection experiments for planetary missions and determining their applicability. Potential experiments are evaluated, and scientific breadboards are then constructed to test the principles. The current efforts stress optical and wet operations combined with chemical and spectroscopic methods.

CURRENT EFFORTS

The isotopic H_2O^{18} experiment has been further pursued, the goal being to develop a new technique appropriate for use as a planetary experiment. The detector for this experiment makes use of the general purpose mass spectrometer developed on another task (see JPL 383-31001-2-3260). At present, the soil sample can be added to the labelled water, incubated, and the organisms subsequently oxidized to CO_2 and H_2O. This can be performed as a two step operation. Attempts to trace the path of the H_2O^{17} have shown that a small fraction becomes incorporated into the tissue. The oxidation of the organic fraction results in O^{18} in both the CO_2 and H_2O fraction. The H_2O^{18} fraction can be reconverted to CO^{18} using 1, 1 prime carbonyl di imidazole. A scientific breadboard has been designed and will be fabricated in FY 1968. This effort will be transferred to the microbiology task in the next fiscal year.

Efforts towards developing a flying spot histochemical experiment have been continued. Some mechanical corrections have resulted in improved performance. A contract has been negotiated with the University of Alabama to develop a microspectropolarimeter. Using a sensitive method for measuring optical rotary dispersion that has been developed, this effort will be devoted to examining its usefulness for a microscopic specimen. This effort will be transferred to a new task, "Imaging and Microscopy," for FY 1968.

Cooperation with the engineering effort to develop an efficient surface sampler for Mars has resulted in a contractual effort to test certain mechanisms on a variety of surfaces. The samples that are collected will be assayed for organic and biological contents. During FY 1968, this effort will be monitored by the Voyager study effort.

PUBLICATIONS DURING REPORT PERIOD

Meetings and Symposia Papers

1. Soffen, G. A., "Microscopy for the Detection of Microorganisms on Mars," New York Academy of Science, June 1967.

ANTICIPATED PUBLICATIONS

None.

EXOBIOLOGY INSTRUMENTATION

NASA Work Unit 189-55-02-04-55
JPL 386-51401-2-3220
J. R. Clark

OBJECTIVE

The long-range objective of this work unit is to develop analytical instrumentation techniques suitable for wet chemical analysis of planetary soils. This report period has emphasized control circuitry required to automate basic chemical setups and processes. Techniques for performing valving, pumping, metering, mixing, and fluid storing are presented.

PROCESS CONTROL CIRCUITRY

Waste Pump Control (Fig. 1)

The requirement is to operate a pump through one cycle for each positive-going level change. This circuit has the advantage of dynamic braking of the motor via transistor Q_3. Initially motor current is supplied by transistor Q_2 and after the cam drives the cycle switch off the cam lobe, motor current is supplied by transistor Q_3. Also, the input command is now inhibited so that motor shutoff and braking are controlled by the cycle switch.

Valve Position Control (Fig. 2)

The requirement here is to be able to select a valve position so that the correct fluid can be extracted. An input current for the desired position is applied to the transistor. The motor is now provided with a return, thus driving the rotor of the attached switch until the return is opened by the notch in the rotor disc. Thus the desired position has been selected.

Test Cell Plunger Control (Fig. 3)

This circuitry controls the filling and emptying of the test cell and the mixing process of two fluids. To fill or empty the test cell a positive-going level change is applied at the designated command input. When the test cell is full or empty, the appropriate limit switch will open preventing mechanical damage. This circuit arrangement allows bidirectional motor control from a single power supply. When mixing is required, the test cell plunger is cycled back and forth a given number of times. To accomplish this action, positive feedback is introduced so that the system functions as an oscillator. In this mode of operation, fill and empty commands are supplied by the bistable multivibrator. Every time a limit switch is actuated the bistable multivibrator is toggled. The mixing operation can be controlled by counting the number of times the full limit switch actuates and after a predetermined number of mix cycles the mix inhibit signals can be applied to terminate the mixing.

Fluid Proportioning (Fig. 4)

This is accomplished by counting the number of revolutions made by the test cell plunger drive gear (see Figs. 4 and 5). The counter is released from preset at the time of required turns counting. The count switch toggles the bistable multivibrator giving an output that is free from switch contact bounce. The counter then accumulates the revolution count and the detector can be connected to give an output after a predetermined number of revolutions.

Fluid Sample Control (Fig. 5)

The figure shows a fluid accumulator that takes a representative sample every time the sample command is received. The accumulator piston is mounted on a lead screw similar to the plunger drive assembly depicted in Fig. 3. It is also controlled in a similar fashion. In this case, however, the fill command is interrupted at the completion of each sample or revolution of the driving gear. This is accomplished by the cycle switch. A motor brake is provided every time the fill command is interrupted. A dump command is applied when it is desired to make an analysis of the accumulated fluid. This causes the motor to drive in the reverse direction thus emptying the accumulator. When the accumulator is empty, the empty command is interrupted and motor braking is applied. The signal to cause empty command interruption is derived from the empty limit switch. A milestone chart indicating the schedule established for this work unit is shown in Fig. 6.

Future Activities

Work on other control problems such as those associated with fluid transport filtration and phase separation is planned for FY 1968.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

JPL SPS Contribution

1. Clark, J. R., "Development of Wet Chemical Process Control Circuitry," SPS 37-45, Vol. IV.

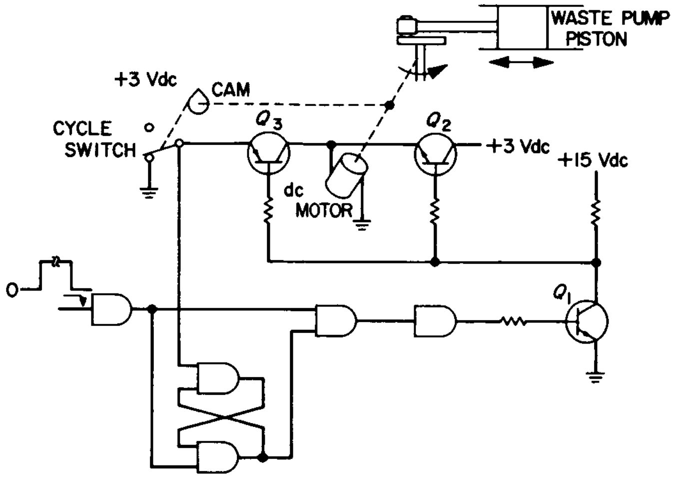

Fig. 1. Waste pump cycle control

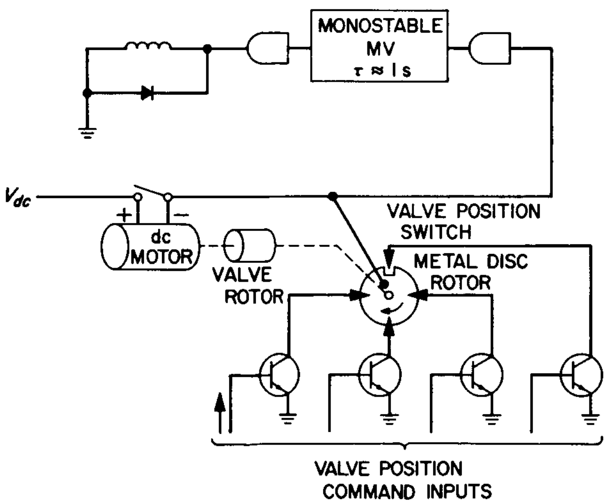

Fig. 2. Valve position control

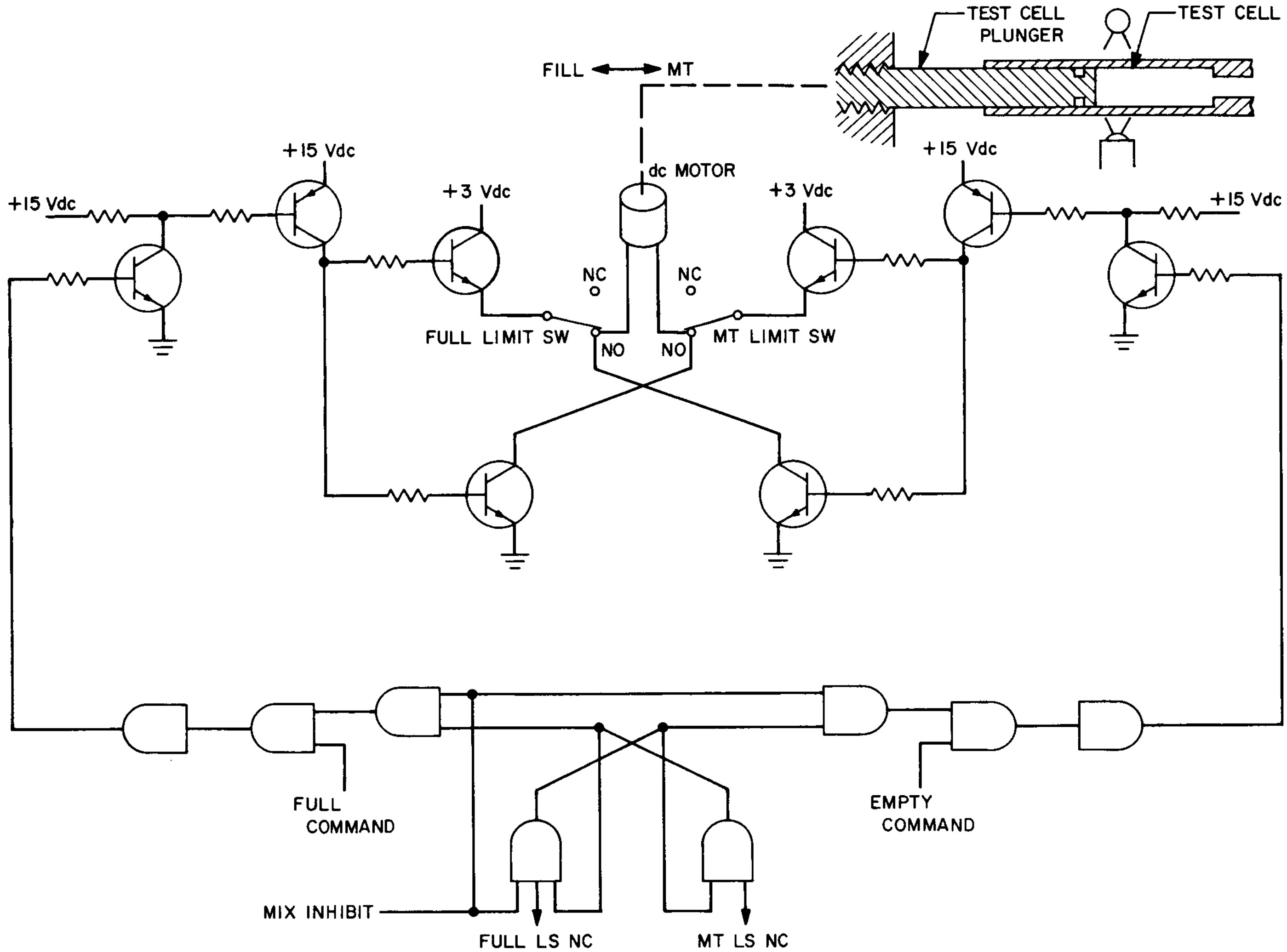

Fig. 3. Test cell plunger control

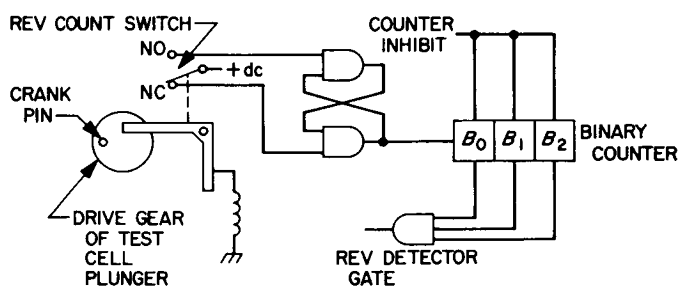

Fig. 4. Revolution counting for metering of fluids

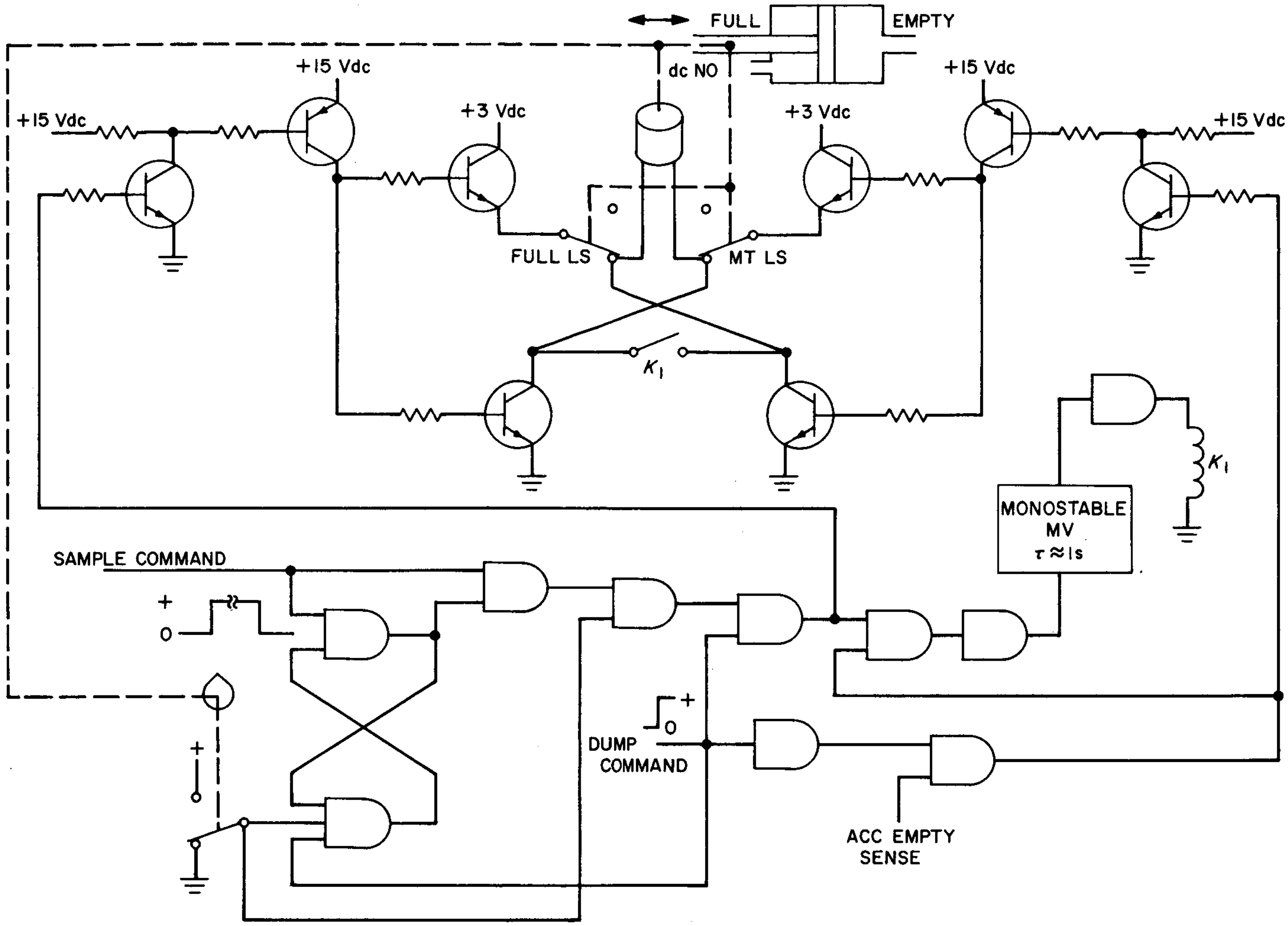

Fig. 5. Fluid sample control

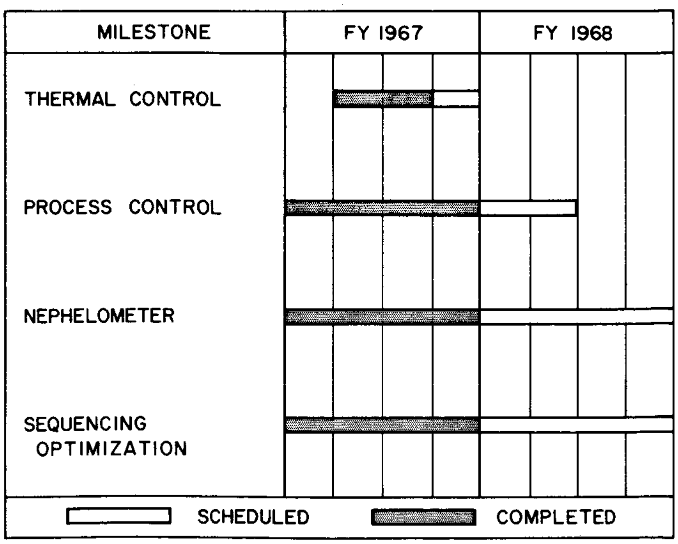

Fig. 6. Milestone chart for exobiology

DETECTION OF LIFE-RELATED COMPOUNDS
NASA Work Unit 189-55-02-08-55
JPL 386-51201-2-3260

C. H. Stembridge

OBJECTIVE

The objective of this work is to provide information for use in defining a technique for detecting the presence and nature of organic compounds in a planetary surface. The analytical procedure being developed is based on the combined techniques of gas chromatography and mass spectrometry. The procedure being followed is: (1) thermal treatment of the sample to yield volatile fragments, (2) separation of these volatiles by gas chromatography, and (3) mass spectrometric determination of the components present in each gas chromatograph peak. In addition, differential thermal analysis of a surface sample will be performed in both oxidizing and reducing atmospheres to detect a disequilibrium between the surface and the atmosphere, and to provide some information on the nature of the inorganic part of the surface material.

PYROLYSIS STUDIES

Studies are continuing on the techniques of pyrolysis. A pyrolyzer has been developed which uses the pyrolyzer tube both as a container for the sample as well as the heat source. It offers a wide range of programming, being capable of heating rates from 1 to 2000°C/min. This pyrolyzer is under evaluation.

Studies involving the injection of pure compounds into the GC/MS as well as pyrolysis studies have revealed that oxidation of the injected materials (or pyrolysis products) takes place in hot regions of the instrument (such as in the separator which is at 270 to 300°C). The source of the oxygen is the high purity helium carrier gas which has about 2 part/10^6 of O_2 impurity. Steps are being taken to eliminate this source of confusion as to the nature of the pyrolysis products.

A preliminary evaluation of the use of hydrogen as the carrier gas indicates that reduction of the compounds in the system is taking place.

ORGANIC ANALYSIS

In operational terms soil organic matter may be classified as either easily extractable recent material or as difficultly or hydrolytically extractable old material. We are attempting to understand the nature of the organic moieties in each case and to develop an analytical system which will give us a complete material balance on soil organic carbon. A TLC survey system has been developed which works well with extracts of all desert soils. We have also isolated some "humic acids" from desert and other soils with the aim in mind of studying both the extraction methodology and the chemical nature of the products.

Because desert algal crust soils seem to yield simple organic extracts which chiefly consist of pigments, we have developed a general TLC method for plant pigments. Published work deals either with carotenoids or with chlorophylls (Ref. 1), but seldom with both (Refs. 2 and 3). There does not appear to be any work published

on the complex degradation products that result from the oxidation of both pigment classes. Our work shows that algal crust soil extracts consist to a large extent of such products.

DTA STUDIES

In order to increase sensitivity in the detection of the exothermic reaction of the oxidation of organic matter in desert soils as observed by DTA, the instrument programming rate was increased to 80°C/min. This represents the maximum heating rate obtainable with the laboratory instrument, which is designed to operate at 10°C/min. The exothermic reactions of desert soils are sufficiently enhanced so that the organic matter in these soils can readily be determined. Inorganic mineral reactions are to some extent similarly enhanced by an increase in sensitivity.

A brief survey into the high-temperature hydroxyl minerals indicates that these mineral reactions, while not generally used for identification in routine examination by DTA because of the availability of other techniques, are readily observable at the moderately high programming rate and result in characteristic peaks that can be used for identification and determination of high-temperature chemically bound water.

After modification and realignment for ambient pressure operation, the lunar DTA breadboard assembly (Ref. 4) has been used to perform high-speed DTA analyses at heating rates to 1200°C/min. Baseline drift, which has previously been considered to be the limiting factor for high-speed analysis, appears to improve with the rate of programming (Fig. 1). Multiple reaction overlap appears to become excessive at 1200°C/min for this particular thermal head design, with an apparent optimum in the 300 to 400°C/min range. Sensitivity is increased by approximately an order of magnitude over normal heating rates (Fig. 2).

HIGH-RESOLUTION MASS SPECTROMETER

Since the last semiannual report considerable progress has been made in improving the performance of the instrumentation. In addition, the system was thoroughly analyzed to locate weak areas where improvements could be made. In connection with this analysis the following steps were taken: (1) All electronic chassis were inspected and defective or marginal components were replaced. The chopper amplifier system is being replaced. (2) The manufacturer has installed a clamping system to tie the analyzer system and the magnet together rigidly. (3) A new vacuum system has been constructed and tested and will be installed soon.

Once the machine had been brought into a condition where a reasonable number of data had been obtained, it became obvious that none of the existing programs for computer evaluation of mass spectra was directly applicable to our situation, in which we have electrically recorded spectra containing many partially resolved multiplets and metastables along with noise. Therefore, we have developed more sophisticated "software" techniques which allow us to extract the useful information in the presence of a significant amount of noise. After investigating several routines, we settled on the one described in the report of May 8, 1967 (JPL Contract 951538) prepared by the Federal Systems Center - West Coast Operations of IBM. The program, based upon these mathematical routines, has been coded as well as the previously established routines of mass determination and elemental composition calculation. The entire program has been debugged with simulated data, and we have just entered the final stage of debugging with refinement, using real data from the mass spectrometer. It

is expected the final peak logging and conversion program will be operational by the middle of July 1967. In addition, we have developed a simplified program as a by-product of our edit program. This routine provides us with the approximate masses of each peak with an accuracy of better than ±25 milli-mass units which is sufficient for a large number of problems resulting from Pyrolysis-GC-MS. This program is also suitable for handling the output from low-resolution mass spectrometers.

During the rather limited periods when the machine was operating and not in use producing data for computer and/or noise reduction studies, we started on our job of studying the application of the mass spectrometer to the identification of biologically important compounds in soil matrices. Due to the immediate availability of samples as well as their general importance, we selected for our first experiment free oligopeptides, amino acids, and simple nucleotides. Most of these compounds previously have been run in the form of derivatives because of a variety of side reactions of the free compounds. However, preliminary results of our investigation have shown that useful information can be extracted from the spectra of these model compounds by themselves.

REFERENCES

1. Schanderl, S. H., "Separation of Chlorophylls and Related Plant Pigments by Two Dimensional Thin-Layer Chromatography," Lynn Co., D. Y. C., and J. Chromatography 26, 442-448 (1967).

2. Smith, L. W., Breidenbach, R. W., and Rubinstein, Daniel, "Thin Layer Chromatography of Plant Pigments on Mannitol or Sucrose," Science, 148, 508-509 (1965).

3. Hager, A., and Meyer-Bertenrath, T., "Extraction and Quantitative Determination of Carotenoids and Chlorophylls of Leaves, Algae and Isolated Chloroplasts with the Aid of Thin Layer Chromatography, Planta (Berlin), 69, 198-217 (1966).

4. SPS 37-31, Vol. IV, pp. 255-261, February 28, 1965.

PUBLICATIONS DURING REPORT PERIOD

Meetings and Symposia Papers

1. Boettger, H. G., "An Advanced Data Processing System for Fast Scanning High Resolution Mass Spectrometers," 15th Annual Conference on Mass Spectrometry and Allied Topics, May 14, 1967, Denver, Colorado.

JPL SPS Contributions

1. Bollin, E. M., "Triaxial Jet Hydrogen Flame Ionization Detector," SPS 37-44, Vol. IV, pp. 236-239, April 30, 1967.

CURVE	MG	SOIL No.	LOCATION	TOTAL ORGANIC MATTER %
A	20	1-2	THERMAL, CALIF	0.4
B	185	297	EGYPT, EASTERN SAHARA	0.2
C	17	291	CHILI, ATACAMA	0.06
D	20	76-1	MOJAVE DESERT	0.9

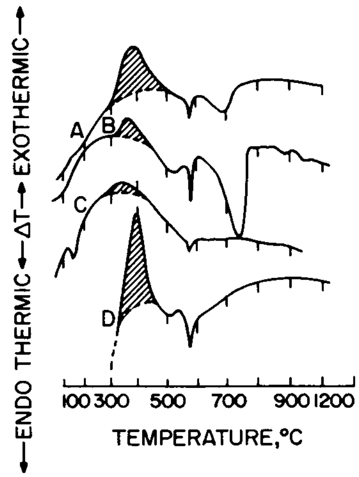

Fig. 1. Moderately high-speed DTA of desert soils, 80°C/min, 66 cc air/min

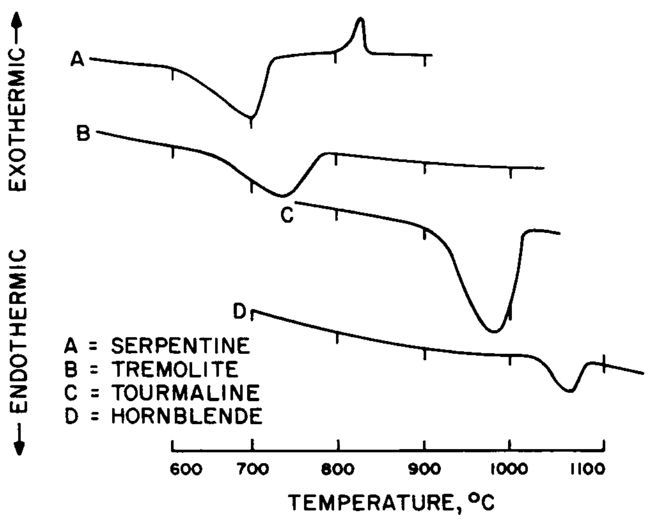

Fig. 2. DTA high-temperature hydroxyl reactions

DESERT MICROFLORA
NASA Work Unit 189-55-04-01-55
JPL 386-50301-1-3260
R. E. Cameron

OBJECTIVE

The long-range objective is to study and identify basic and specialized groups of microflora in harsh environments, especially desert soils, in relation to unmanned planetary exploration for life.

INVESTIGATIONS IN ANTARCTICA

Soil samples were collected from the surface to approximately 1-ft deep at the level of hard, icy permafrost at 25 sites in Antarctic "dry valleys." Four samples were analyzed. The greatest number of bacteria were found at the surface and just above the top of the permafrost layer. Far fewer bacteria, 10 to 100/g of soil, were found in the Antarctic soils than in typical U.S. desert soils. Yeast, bacilli, and cocci (aerobes and microaerophiles) were found between the surface and hard permafrost.

Additional studies will be made in Antarctic "dry valleys" during November-January 1967-68. In situ measurements will be made for environmental properties, e.g., H_2O, temperature, CO_2, and O_2, relative to activity of microorganisms and the abundance of microorganisms determined. Samples will be collected from salt ponds, previously contaminated sites, as well as from traverses from valley floor to rims of valleys. Frozen samples will be returned to JPL for additional studies.

CHILEAN ATACAMA DESERT SOIL SAMPLES

Five samples of soil were recently collected and received from northern Chile. These samples are showing growth response times and abundance of microflora on routine culture media; e.g., trypticase soy agar, typical of U.S. desert soils, which is contrary to samples previously analyzed from Chile. Physically and chemically, these soils are the same as soils previously collected in Chile. It may be that the interval between time of collection and analysis is a crucial factor. Effects of storage time, storage environment, and abundance of microflora will be given further study on previously characterized and stored California desert soils.

CONTRACTS

Cultural and identificational studies of desert bacterial and streptomycete isolants have been continued under JPL Contract 950783 with Prof. Walter Bollen as principal investigator, at Oregon State University, Corvallis, Oregon. Detailed, illustrated reports have been received for preliminary isolants from Chilean Atacama Desert soils and from old stored Hilgard Museum soils. Very few of the Chilean samples retained their viability upon retransfer to test media. Survivors were primarily identified as Bacillus spp. The isolants from the Museum soils were 75% identifiable Baccillus spp. and 15% soil diptheroids. Sixty-six additional isolants from Antarctica and Chile have been sent for study.

Cultural and identification studies of desert fungi and yeast have been continued under JPL Contract 951602 with Prof. Eugene Staffeldt, principal investigator at New Mexico State University, Las Cruces, New Mexico.

Preliminary reports have been received for 150 isolants of fungi. Most of the fungi are Penicillium or Aspergillus spp. Thirty-eight additional isolants have been sent from Chile, Egypt, and Antarctic soils, and 21 additional soils for cultural studies have been sent for sites in desert areas of Arizona, Nevada, New Mexico, and Mexico.

A proposal from Dr. Gilbert Levin, Biospheric Research, Inc., Washington, D.C., is being considered for the next fiscal year. According to this proposal, 200 desert soils will be analyzed by methods under consideration for extraterrestrial life detection utilizing "Gulliver" and "Diogenes" life detectors.

PUBLICATIONS DURING REPORT PERIOD

Meetings and Symposia Papers

1. Benoit, R. E., and Cameron, R. E., "Microbial Ecology of Some Dry Valley Soils of Antarctica," American Society for Microbiology, New York, New York, May 1, 1967.

Publications in the Open Literature

1. Benoit, R. E., and Cameron, R. E., "Microbial Ecology of Some Dry Valley Soils of Antarctica," Bacteriology Proceedings, Abstracts of the 67th Annual Meeting, p. 3, 1967.

JPL SPS Contributions

1. Cameron, R. E., "Soil Studies - Desert Microflora, XIV. Soil Properties and Abundance of Microflora from a Soil Profile in McKelvey Valley, Antarctica," SPS No. 37-44, Vol. IV, April 30, 1967.

JPL Technical Memorandum

1. Cameron, R. E., Blank, G. B., and Horowitz, N. H., Growth of Aerobic and Anaerobic Bacteria in Agar Subjected to Freezing and Diurnal Freezing and Thawing, TM 33-331, June 15, 1967.

Contractor Reports

1. Bollen, W. B., Ammonifying, Nitrifying, and Sulfur Oxidizing Capacity of Chile Desert Soils, Oregon State University, May 31, 1967 (JPL Contract 950983).

2. Bollen, W. B., Identification of Chile Atacama Desert Soil Isolants, Oregon State University, June 6, 1967 (JPL Contract 950983).

3. Bollen, W. B., Systematic Description and Key to Isolants from Hilgard Soils, Oregon State University, June 12, 1967 (JPL Contract 950983).

ANTICIPATED PUBLICATIONS

Open Literature

1. Cameron, R. E., and Blank, G. B., "Desert Soil Algae at Extremely Low Temperatures," Cryogenic Technology, in press, May-June 1967.

2. Benoit, R. E., and Cameron, R. E., "The Microbial Ecology of Some Dry Valley Soils of Antarctica," Bacteriology Reviews, paper near completion.

MICROBIOLOGY STUDIES

NASA Work Unit 189-55-04-03-55
JPL 386-50601-2-3260
J. S. Hubbard

OBJECTIVE

The objective of these microbiological studies is to support the life-detection program. The indications that the surface of Mars contains limited quantities of water poses special problems in measuring the growth and metabolism of Martian life forms. Experiments with osmophilic and halophilic organisms were conducted in order to devise methods for measuring metabolism in environments of limited water and to characterize the forms of metabolism which are functional in such environments. Other experiments have been initiated to determine the physiological properties that enable microorganisms to survive and proliferate in the harsh environments of the Atacama Desert and Antarctic dry valleys.

GROWTH AND METABOLISM OF OSMOPHILIC AND HALOPHILIC ORGANISMS

The osmophilic yeast, Saccharomyces mellis, grows only in media of high solute content. This requirement may be fulfilled by providing high levels of a metabolizable substrate such as glucose or by providing a low level of glucose in conjunction with high levels of nonmetabolizable solutes such as glycerol or sucrose. The high osmotic pressure does not serve to protect the cells from physical damage. In harsh environmental studies, biosynthesis could be detected using cells suspended in 63% (by weight) of glycerol. This activity was demonstrated by providing the cell suspensions with ^{14}C-labelled glucose or amino acids and measuring the radioactive incorporation into cellular proteins and nucleic acids. In the previous semiannual report it was stated that biosynthesis could be detected with cells suspended in 88% glycerol or propylene glycol. However, subsequent investigations revealed that the radioactive substrate was physically adsorbed to the cells in the 88% solute medium and this adsorption was not related to the metabolic processes.

Experiments with cell-free extracts of S. mellis have shown that the activities of intracellular enzymes are adversely affected by high osmotic pressure. The activities of the hexokinase, glucose-6-phosphate dehydrogenase, and glutamate dehydrogenase were inhibited by solute concentrations which are optimal for growth. Lesser degrees of inhibition were caused by lower solute levels, but in no case was a stimulation in activity observed. If the results of enzyme experiments are indicative of cellular metabolism, then it might be concluded that the environment of the intracellular enzyme is different from that of the external medium. One explanation is that the cells carry out a concentrative uptake of water from the high solute medium.

Enzyme experiments have also been conducted with two halophilic bacteria, a Chromatium species which grows photosynthetically in an inorganic salts medium and Halobacterium cutirubrum which grows heterotrophically. The glutamate dehydrogenase and isocitrate dehydrogenase of the Chromatium were inhibited by salt concentrations which are optimal for growth. In contrast, with H. cutirubrum these two enzymes were dependent on the high ionic strength for activity. With the isocitrate

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dehydrogenase the salt serves a dual role, to activate the enzyme and to protect against denaturation. Experiments are in progress to purify and characterize the H. cutirubrum isocitrate dehydrogenase.

PHYSIOLOGY OF DESERT SOIL ORGANISMS

A variety of procedures has been applied to the isolation of microorganisms from the soils of the Atacama Desert and dry valleys of Antarctica. The conditions were designed for the isolation of aerobes and anaerobes using several media with four incubation temperatures. With the Atacama soils the highest number of isolates were obtained on glucose-salts-soil extract medium. Rich organic media gave considerably lower yield. With either the Atacama or Antarctic soil, incubation at 15°C favored the growth of pigmented species. Preliminary results have indicated that the population of anaerobes is small in the soils of either site.

One Antarctic isolate has been selected for more detailed study. This aerobic, gram negative coccus was isolated from a subsurface soil in the McKelvey Valley. The optimum growth temperature for the coccus is about 20°C, although abundant growth is attained at 4°C. An incubation temperature of 31°C is inhibitory for growth. A defined medium for the coccus consists of salts mixture containing three amino acids as the carbon and energy source. Physiological studies with this and other isolates will be continued. It will be of interest to determine if such organisms can carry out metabolism under environments simulating those from which they were isolated.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

JPL SPS Contributions

1. Hubbard, J. S., and Miller, A. B., "Limitations of Water on the Metabolism of Osmophilic Yeasts" (in preparation).

PLANETARY QUARANTINE/STERILIZATION (189-58)

STERILE INSERTION TECHNIQUES
(FORMERLY STERILE ASSEMBLY TECHNIQUES)

NASA Work Unit 189-58-21-01-55
JPL 386-82201-2-2945

G. H. Spruce

OBJECTIVE

Sterile insertion techniques concern the problem of maintaining sterility during insertion of previously sterilized components into a spacecraft. It is possible that some components may be heat-labile and therefore unable to survive the terminal "heat-soak" process. It would thus be necessary to treat these materials separately and install them subsequent to vehicle sterilization.

The objective of this task is to develop techniques of inserting separately sterilized components into a sterile spacecraft without compromising sterility and, further, to develop challenges that will demonstrate the reliability of these techniques.

APPROACH

It is planned to initiate a contract under which all applicable current technology may be studied, consolidated, modified, and/or developed into reliable techniques and procedures for the sterile insertion of sensitive equipment. These techniques to be evaluated include the sterile air curtain, sterile slit, and "remote" manipulation techniques.

These studies will result in the recommendation and selection of a technique or combination of techniques through the use of which sterile insertion may be accomplished. The contractor will be required to demonstrate mechanical feasibility of such techniques as well as the challenges thereto. Proof of biological feasibility is, necessarily, a lengthy statistical analysis and does not form a part of the contracted study described here.

ACCOMPLISHMENTS TO DATE

A procurement requisition (385099) has been issued, following a critical and comprehensive evaluation of current techniques for sterile insertion, repair, and assembly. This evaluation encompassed all currently discernible technology which could provide applicable ideas, and spanned such diverse industries as the pharmaceutical, petrochemical, aerospace, and medical, as well as research and educational facilities; in short, any process where contamination-problem solutions may prove helpful.

This requisition was issued in the fourth quarter of FY 1967 and describes a study of one year's duration which will ascertain and develop the basic techniques of sterile insertion.

FUTURE ACTIVITIES PLANNED

Current plans call for the followup of this study with a second contract which will delineate detailed procedures, within these general techniques. Such procedures will provide the level of reliability required of this task. An integral part of these studies, of course, is the development of challenge tests to determine the precise efficiency and reliability of those techniques and procedures so developed.

Additionally, a continuing investigation and evaluation of newly developed techniques from all applicable sources will be conducted, and promising elements will be factored into these studies as time and contract restraints allow.

PUBLICATIONS DURING THIS REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

REVIEW OF HEAT AND ETHYLENE OXIDE SPECIFICATIONS

NASA Work Unit 189-58-21-02-55
JPL 386-82301-2-2945

A. S. Irons
W. W. Paik
A. Hoffman

SUBTASK I — ETHYLENE OXIDE DECONTAMINATION PROCESSES

Objective

The objective of the proposed task is to develop necessary parametric information to be used for establishment of appropriate ethylene oxide cycles for decontamination of specific spacecraft designs. Materials compatibility and system continuity problems of the design will present limiting constraints on the duration of the humidification cycle and on the time, temperature, relative humidity, and ethylene oxide concentration of the process. Information concerned with the effects on process efficiency of varying process parameters must be established under physical conditions simulating those which will be used for spacecraft treatment. Additional information required may include the flow patterns and diffusion rate of ethylene oxide over and into various spacecraft components and assemblies under the physical conditions to which the space hardware will be subjected.

It will also be necessary to develop ethylene oxide decontamination process specifications and procedures to be used for decontaminating space hardware.

Discussion

The sterilization and decontamination constraints imposed on an object--its composition, configuration and size, as well as the size and type of microbial burden associated with the object--all directly affect the sterilization process and the equipment required to render it sterile. In the case of a sterilization chamber, it must be somewhat larger than the object it houses to permit free movement of the sterilizing agent being used. It must also be equipped, to apply and control the agent being used, in such a manner as to ensure maximum destruction of organisms. The sterilizing agent used may be a hot moist gas such as stream, a hot dry gas such as nitrogen, or a chemical sterilant such as ETO, depending on the compatibility of the material being exposed.

When ethylene oxide gas is used as a sterilizing agent, major problems arise due to the physical properties of the gas and the special equipment required to ensure its effectiveness; for example, the size and configuration of certain space hardware makes it difficult to heat and humidify. Controlled heating of a large object or load is a problem, but is necessary in order to increase the effectiveness of the ETO, thus decreasing the exposure time. Moisturization is also a problem because space hardware will be exposed to the dehydrating effect of high vacuum during environmental test, and the dehydration of microorganisms makes them more resistant to ethylene oxide. These and other parameters such as ethylene oxide concentration and time of exposure will be investigated, all aimed at increasing the efficiency and reliability of the proposed ethylene oxide process.

Considerable information is available on the use of ethylene oxide as a decontaminant or sterilant for pharmaceutical and medical products. However, the adaptation of this information to the problem of space hardware decontamination requires additional work because of the large physical size of the spacecraft and compatibility problems of spacecraft hardware with the physical conditions to which the space hardware must be subjected during the decontamination process.

Approach

The approach which will be used to solve the problems involved will be an investigation of the effects on process efficiency of varying the parameters of temperature, humidity, ethylene oxide concentration, pressure, and duration of the humidification cycle, under conditions simulating those which will be used for spacecraft treatment (for example, see Fig. 1).

The proposed variations will be evaluated by inoculating standard surfaces such as glass, stainless steel, and actual space hardware with microorganisms and subjecting the surfaces to a complete cycle. Recovering and counting the viable organisms remaining after exposure will give an indication of the relative efficiency of the cycle. Data utilizing recovery and enumeration of viable spores, as well as attribute (go/no-go) data may be used in evaluating the effects of varying the parameters.

A contract will be issued to evaluate the effects of the stated variations. This may require the fabrication of equipment capable of producing the conditions required and the use of space hardware test pieces. It is important that space hardware be used in the evaluations because very little work has been done on actual hardware and, as a result, very little information is available on the effect of cycle variations on these items.

Accomplishments to Date

When this task was initiated in FY 1966 a work statement was prepared for evaluation of a specific cycle (JPL process), a Procurement Requisition was sent to Procurement, and a Request for Proposal was issued. Several proposals were received and were being evaluated when it was decided to cancel the work statement as written because of a change in the scope of the program, but to leave the funds committed. Proposers were advised of the change.

During this report period, a new work statement was prepared which reflected the change in scope. The work statement calls for a study to determine the effects upon process efficiency of varying the process parameters (temperature, relative humidity, ethylene oxide concentration, pressure, carrier gas, and duration of the humidification cycle) under conditions simulating those which will be used for the spacecraft hardware treatment. Recovery of organisms from test specimens and the determination of the viability of the recovered organisms will provide the means of measuring relative efficiency.

Procurement was initiated April 19, 1967.

Request for Proposal EC4-6810 was issued on May 4, 1967 and was sent to eleven companies. The response deadline was set at June 26, 1967. No information regarding respondees is available at the time of this writing.

Planned Future Activities

After evaluation of the proposals received, appropriate procurement action will be taken to issue an incrementally funded contract of approximately 12-mo duration. As a result of this contract, an Ethylene Oxide Decontamination Process Document and an Ethylene Oxide Decontamination Requirements Document will be released during the third and fourth quarters of FY 1968, respectively. A follow-on contract will be initiated during the fourth quarter of FY 1968 for the development and verification of procedures and the verification of the process efficiency using simulated flight hardware. This contract (which will be completed during the first half of FY 1969) will result in a Final Ethylene Oxide Decontamination Process Document which will be released in the third quarter of FY 1969.

The current schedule calls for initiation of work approximately September 26, 1967.

SUBTASK II -- REVIEW OF HEAT SPECIFICATIONS

Objective

The objectives of this task are (1) to perform continuing research on the dry heat resistance of selected microorganisms and to pursue any developments stemming from this present research, and (2) to perform analyses of various factors influencing the terminal sterilization process parameters.

Discussion

It is anticipated that the terminal sterilization process used to satisfy NASA planetary quarantine requirements will be dry heat. The total time at temperature of any dry heat sterilization process is dependent upon several factors, including the characteristics of the heating medium and the thermal resistivity of the microorganisms.

Approach

During this reporting interim, an effort to determine the effects of different spacecraft material surfaces upon the heat resistance of bacterial spores was conducted. The procedures used in this effort were as follows:

(1) The required number of test strips are inoculated with bacterial spores.

(2) The strips are placed in a vacuum desiccator containing dried silica gel after drying and stored for 16 h at 24 in. of negative pressure.

(3) The test strips are then suspended from an aluminum support mechanism in a preheated (125°C) dry air oven.

(4) The first assay is conducted at that time necessary for the strips to reach test temperature.

(5) After heat exposure for the desired time period, the test strips are placed in bottles containing prechilled (0 to 4°C) recovery medium.

(6) The bottles are placed within an ultrasonic bath and sonicated at 25 kc/s for 12 min. Appropriate dilutions are made and aliquots are plated in Trypticase Soy Agar. Plate counts are made after aerobic incubation at 32°C for 72 hr.

Accomplishments To Date

Utilizing the described method, eight different materials have been evaluated as to their effects upon the dry heat resistance of B. subtilis var. niger spores. These materials and the resultant test values are shown in Table 1.

As can be seen in Table 1, there does not appear to be a significant difference in the D values for B. subtilis var. niger spores on the various materials. The D values vary from 16.0 min for two of the stainless steel tests to 21 min for spores on Cat-A-Lac Paint. This slight variation in D values is believed to be inherent to the test procedure utilized. The D values for stainless steel range from 16.0 to 20.0 min. This degree of variability in D values for spores on the same surface tends to substantiate that the reported differences in thermal resistivity for the bacterial spores tested are due to slight procedural variations rather than to the different material surfaces used as carriers. However, the materials tested to date all represent relatively smooth, even-textured surfaces. The effects of such material characteristics as water and heat retention, and porosity, upon the thermal resistivity of bacterial spores have not been determined.

Work within the area of identifying various factors which affect sterilization process time deviations was continued during this reporting period. A mathematical model was formulated and various analyses performed. This work demonstrated that integration of the lethal effects of the transient phases (the heating and cooling portions) of the process would significantly affect the process parameter of time at temperature when compared to the process time at the same temperature where the lethal effects of the transient phases are not considered. A second phase of this study considered the effects of the distribution of microorganisms upon the spacecraft on the duration of the sterilization process time.

As a result of this work, a series of recommendations concerning sterilization process times was made to the Spacecraft Sterilization Advisory Committee and is now receiving consideration.

Future Activities Planned

Additional spacecraft materials will be evaluated as to their effects, if any, upon the thermal resistance of bacterial spores. An effort will also be expended to determine the effects of different mated surfaces upon bacterial thermal resistivity. The work to identify and analyze the influence of various process variables upon sterilization process times will be continued.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

Meetings and Symposia Papers

1. Stern, Joseph A., and Hoffman, Alan, "The Determination of Terminal Sterilization Process Parameters," COSPAR, London, England, July 1967.

2. Hoffman, Alan, and Stern, Joseph A., "Terminal Sterilization Process Calculation for Spacecraft," Society of Industrial Microbiology, Quebec, Canada, August 1967.

SPS Contributions

1. Paik, William, and Stern, Joseph A., "The Dry Heat Resistance of Bacterial Spores on Spacecraft Surfaces," SPS Vol. IV, July 1967.

Table 1. Comparison of D values for *B. subtilis* var. *niger* spores on different material surfaces

Material	D value at 125°C,[a] min
Aluminum alloy, 6061T6	20.5
Magnesium (conversion coated Dow 7), AX31B-H24	20.5
Titanium alloy, 6Al-4V	17.0
Magnesium alloy, AZ31B-H24	19.5
Stainless steel type #302	
Test 1	17.0
Test 2	17.0
Test 3	16.0
Test 4	16.0
Test 5	20.0
Paint, Cat-A-Lac, 436-1-B	21.0
Aluminum, conversion coating, (Iridite 14)	20.0
Gold plating-24 karat gold, electroless nickel	19.0

[a] D (decimal reduction time) is that time, at a specific temperature, that will result in a 90% reduction in the number of viable cells within a single population.

ETHYLENE OXIDE CONCENTRATION ± 50 mg/l CHAMBER VOLUME										
		400			500			600		
		TEMPERATURE C ± 1.5 °C DURING ALL PHASES								
		30	35	40	30	35	40	30	35	40
PERCENT R H DURING EXPOSURE	TIME, h	PERCENT POSITIVE TEST PIECES AFTER PROCESSING FLAT GLASS CAPPED TUBES								
30 ± 2%	4									
	10									
	16									
40 ± 2%	4									
	10									
	16									
50 ± 2%	4									
	10									
	16									

GAS—USED: 88 % FREON 12 % ETHYLENE OXIDE

PREHUMIDIFICATION CONDITIONS:
RH 50 ± 2 % FOR 16 h
TEMPERATURE SAME AS STERILIZATION PHASE

Fig. 1. Partial matrix of data requirements for study of effect of process parameter variation on process efficiency

EVALUATION OF FILTERS FOR STERILIZING LIQUIDS AND GASES

NASA Work Unit 189-58-21-04-55
JPL 386-80301-2-2945

A. S. Irons

OBJECTIVES

This study is designed to evaluate the biological efficiency and reliability of currently available filters. The data from this and other studies will be used to prepare a list of filters which can be used to sterilize and maintain the sterility of liquids and gases.

The data generated during the original period of performance covered two major filter types: the high-efficiency low-pressure air filters and the liquid filters of membrane construction. Two categories are being investigated during the current study; they are (1) evaluation of filters in a pressure gas-flow system and (2) evaluation of filters in a pressurized liquid-flow system.

DISCUSSION

Portions of the dry heat and ETO cycles, biological experiments, and maintenance of a sterile spacecraft require sterile filtration. Liquids required for biological experiments and certain liquid propellants represent a few of the substances that may be degraded by dry heat or chemical sterilization and may require sterilization by filtration. Gases, such as nitrogen, which are carried aboard and used in some attitude control devices may also have filtration requirements to produce sterile gas.

Prior to initiation of this study there was a lack of definitive information relative to the true filtering efficiency of commercially available filters and filter holders when tested under actual use conditions. This applied to filters for liquids as well as gases. This lack of information and our possible need for "cold" sterilization methods for heat-labile substances led to the decision to conduct an in-depth investigation of filters and filtration techniques. A preliminary investigation was made of all the commercially available filters and a list was made of those claimed to be capable of sterilizing liquids or gases or both. The most promising filters and filter assemblies were then chosen for evaluation.

APPROACH

A contract was awarded to Wilmot Castle Co. that called for the following:

(1) Investigation of the cause of liquid filter failure. This includes examination of filter holders as well as filter media and involves the use of two test organisms, i.e., *Serratia marcesens* (Sm) and *Bacillus subtilis* var. *niger* spores (Bg).

(2) Evaluation of liquid or high-pressure gas filters including any which have been developed since the initiation of this study. This includes filters which may have a bacteriostatic effect and which will require special culturing techniques.

(3) Determination of the biological efficiency of liquid filters placed in tandem.

ACCOMPLISHMENTS TO DATE

During this report period filters were evaluated for their ability to sterilize liquids under pressure and forced through the filter system.

Single Holders

Special pressure apparatus had to be fabricated to contain the bacterial suspensions, to which was fitted a pressure gauge, suitable valves, and pressure regulator and piping connections to the pressure filter holders (Fig. 1). The pressure apparatus was entirely flushed and steam-sterilized prior to use. The assembly of filter elements in the filter holders was accomplished within a sterile hood at which time the receiving flask containing the triple strength growth recovery media was fitted to the apparatus.

In the data to follow (Tables 1, 2, 3, and 4) the filters were Selas, Metal Membrane (S.M.M.), Selas Unglazed Porcelain (S.P.), Seitz Asbestos (S.A.), Millipore (M.P.), Gelman (G.), Schleicher and Schuell (S.S.), and others. In all cases the challenge fluid spore count per ml was 100, and the total test volume was one liter. The test organisms were *Bacillus subtilis* var. *niger* spores.

Selas Flotronics Co. claimed their metal membrane, if properly supported, would withstand 15,000 psig and recommended the use of the Millipore holder for the tests regardless of pressure, but under 100 to 200 psig they invariably blew out. Millipore filters could withstand 100 psig but failed at 200 psig. Thus, the Millipore GS and HA filters of 0.22 and 0.45 μ, respectively, and the Schleicher and Schuell B-11, MC-4 had high efficiency in the Millipore holder (Fig. 1) at 100 psig and some were acceptable with the Gelman holder at 100 psig. The Horm filter (Table 3) proved excellent under the constraints of the tests.

Holders in Tandem

The special pressure apparatus which was previously described was used to hold two filter holders in series for the second portion of this study (Fig. 1).

Since the Gelman filter was rated at the higher pressure, it was placed first in the series. In the program for the two-in-series tests, 5 units were run at 100 psig and 5 at 200 psig.

Testing of the first series of the pressure-liquid program was completed with the testing of the Selas and Pall Ultipore filters.

In the data presented in Table 5, the filter holders used were Selas, Unglazed Porcelain (S.P.P.T. 158P2), and Pall Ultipore (Pall), Gelman and Millipore. The filters are designated as Millipore (M.P.), Schleicher and Schuell (S.S.), and Selas metal membrane (S.M.M.). In all cases the total volume tested was one liter. The differential pressure (ΔP) is the same as the total pressure. In all but two cases, the 200-lb pressure was too great for even the double membranes. The exception

was the combination using the S.S., B-6, and B-11 filters. The type of organism used in the serial filtration did not seem to matter.

A total of 380 filters was evaluated. They represented seven manufacturers and twenty types. In addition, five different makes of filter holders were evaluated.

PLANNED FUTURE ACTIVITIES

The ability of filters to sterilize gases in a pressure flow system will be evaluated.

This will be accomplished by nebulizing spores into a pressure vessel containing an inert gas such as nitrogen and then forcing the gas through a membrane filter, or by nebulizing spores into a rapidly moving air stream that will produce the maximum recommended gas flow through the filter being evaluated.

The filters being evaluated will be positioned in the exit lines. The amount of pressure and the pressure drop across the face of each filter will be determined, as well as the flow rate through each filter.

Filters will also be tested and evaluated for filtration of gas under pressure, using two filter holders of different makes in series. The object of these tests is to determine the usefulness of the dual filtration procedure in increasing efficiency and establishing confidence that sterility has been achieved, and to further define the problem areas.

Filters other than membrane filters also will be evaluated. These include:

(1) Pall Corp. - Ultipore ACF gas filter.

(2) Linde gas filter.

(3) Selas porcelain FO-128 - liquid filter.

(4) Seitz asbestos - sterilization grade - liquid filter.

Data from the previous contract will be compiled, evaluated, and assessed for the eventual submission of a final report. This work is extensive in scope and content.

A filtration-requirements document will be prepared and issued in December 1967, based on the results of the present contract and the prior contract, which evaluated the efficiency of HEPA filters.

A follow-on contract of 8-mo duration will be initiated in early FY 1968 for development of procedures to be used for acceptance testing of filters and filtration equipment, and for the definition of actual filtration processes which will be used. The contract will require in use demonstration of procedures efficiency.

The present contract calls for a 54-wk study and is scheduled for completion during August 1967.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Irons, A. S., "Microbiological Evaluation of High-Efficiency Particulate Air (HEPA) Filters," SPS 37-43, Vol. IV, p. 53.

Contractor Reports, Interim

1. Robert R. Ernst, Principal Investigator, Wilmot Castle Co., Rochester, New York. Report No. 6, January 1 - January 31, 1967.
2. Report No. 7, February 1 - February 28, 1967.
3. Report No. 8, March 1 - March 31, 1967.
4. Report No. 9, April 1 - April 30, 1967.
5. Report No. 10, May 1 - May 31, 1967.

ANTICIPATED PUBLICATIONS

None.

Table 1. Test results

Filter manufacturer and type	Holder	ΔP, psig	Filtration time, min			No. Unsterile / No. Tested
			Low	Mean	High	
S.M.M., 0.45μ	M.P.	100	1	6	15	10/10
S.M.M., 0.45μ	G.	200	1	3	5	9/10
S.M.M., 0.20μ	M.P.	100	1	3	65	8/10
S.M.M., 0.20μ	G.	200	1	1	2	10/10
M.P., GS, 0.22μ	M.P.	100	1	1	1	0/10
M.P., GS, 0.22μ	G.	200	0.5	0.5	0.5	10/10
M.P., HA, 0.45μ	M.P.	100	0.5	0.5	0.5	0/10
M.P., HA, 0.45μ	G.	200	0.5	0.5	0.5	10/10
S.S., B-11, 0.25μ	M.P.	100	1	1	2	0/10
S.S., B-11, 0.25μ	G.	200	1	2	5	7/10
S.S., MC-4, 0.25μ	M.P.	100	2	2	3	2/10
S.S., MC-4, 0.25μ	G.	200	1	2	2	10/10

Table 2. Test results

Filter manufacturer and type	Holder	ΔP, psig	Filtration time, min			No. Unsterile / No. Tested
			Low	Mean	High	
S.P., FD-128 015, 0.3 μ	S.P., PT 158-P2	10	2	3	5	0/10
S.P., FD-128 03, 0.1 μ	S.P., PT 158-P2	10	6	11	18	0/10
S.A. Coarse (ST)	Seitz	10	18	23	29	0/10
S.A. Fine (ST-1)	Seitz	10	25	29	33	0/10
S.M.M., 0.45μ	M.P.	10	2	4	5	10/10
M.P., GS, 0.22μ	M.P.	10	6	6	9	0/10
M.P., HA, 0.45μ	M.P.	10	1	2	2	1/10
S.S., B-11, 0.25μ	M.P.	10	6	8	10	1/10
S.S., MC-4, 0.25μ	M.P.	10	6	11	16	1/10
Pall Ultipore ACF-4463	Pall	10	1	1	2	3/10

Table 3. Test results

Manufacturer and type	Holder	ΔP, in. Hg	Filtration time, min			Microbes per/ml	No. Unsterile / No. Tested
			Low	Mean	High		
0.5 μ Horm Filter D-6 (Bg)	Horm	22.0-26.8	5	8	13	100	0/10
0.5 μ Horm Filter D-6 (Sm)	Horm	20.0-27.2	5	9	19	130	0/10
Horm Filter D-10, 01 μ (Bg)	Horm	22.5-27.4	12	15	20	100	0/10
Horm Filter D-10, 01 μ (Sm)	Horm	20.2-26.8	10	18	40	130	0/10
		Pressure, psig					
Horm Filter D-6, 0.5 μ (Bg)	Horm	25	1	2	2	100	0/10
Horm Filter D-6, 0.5 μ (Sm)	Horm	25	2	2	2	120	0/10
Horm Filter D-10, 0.01 μ (Bg)	Horm	25	2	3	4	100	0/10
Horm Filter D-10, 0.01 μ (Sm)	Horm	25	2	3	4	120	0/10

Table 4. Single filtration

Filter manufacturer and type	Holder	ΔP, psig	Filtration time, min			Microbes per ml	No. Unsterile / No. Tested
			Least	Mean	Highest		
Selas Unglazed Porcelain FD-128 03 01 μ	SP P.T. 158-P2	25	3	6	8	100	7/10
Pall Ultipore ACF-4463	Pall	150	0.5	0.5	0.5	100	8/10

Table 5. Double filtration

Filter manufacturer and type 1	Holder 1	Filter manufacturer and type 2	Holder 2	ΔP, psig	Filtration time, min			Microbes per ml	No. Unsterile / No. Tested
					Least	Mean	Highest		
M.P., GS 0.22 μ (Sm)	Gelman	M.P., HA 0.45 μ	Millipore	100	1	1	2	105	0/5
M.P., GS 0.22 μ (Sm)	Gelman	M.P., HA 0.45 μ	Millipore	200	0.5	1	1	105	5/5
M.P., GS 0.22 μ (Bg)	Gelman	M.P., HA 0.45 μ	Millipore	100	1	1	2	100	0/5
M.P., GS 0.22 μ (Bg)	Gelman	M.P., HA 0.45 μ	Millipore	200	0.5	1	1	100	4/5
S.S., B-6 0.4 μ (Sm)	Gelman	S.S., B-11 0.25 μ (Sm)	Millipore	100	1	1	2	120	0/5
S.S., B-6 0.4 μ (Sm)	Gelman	S.S., B-11 0.25 μ	Millipore	200	1	1	1	120	0/5
S.S., B-6 0.4 μ (Bg)	Gelman	S.S., B-11 0.25 μ	Millipore	100	2	2	2	100	0/5
S.S., B-6 0.4 μ (Bg)	Gelman	S.S., B-11 0.25 μ	Millipore	200	1	1	1	100	0/5
S.M.M., 0.45 μ (Sm)	Gelman	S.M.M., 0.20 μ	Millipore	100	10	29	43	120	5/5
S.M.M., 0.45 μ (Sm)	Gelman	S.M.M., 0.20 μ	Millipore	200	0.5	1	1	120	5/5

Table 5. Double filtration (cont)

Filter manufacturer and type 1	Holder 1	Filter manufacturer and type 2	Holder 2	ΔP, psig	Filtration time, min			Microbes per ml	No. Unsterile / No. Tested
					Least	Mean	Highest		
S.M.M., 0.45 μ (Bg)	Gelman	S.M.M. 0.20 μ	Millipore	100	7	53	53	100	5/5
S.M.M., 0.45 μ (Bg)	Gelman	S.M.M., 0.20 μ	Millipore	200	1	1	5	100	5/5

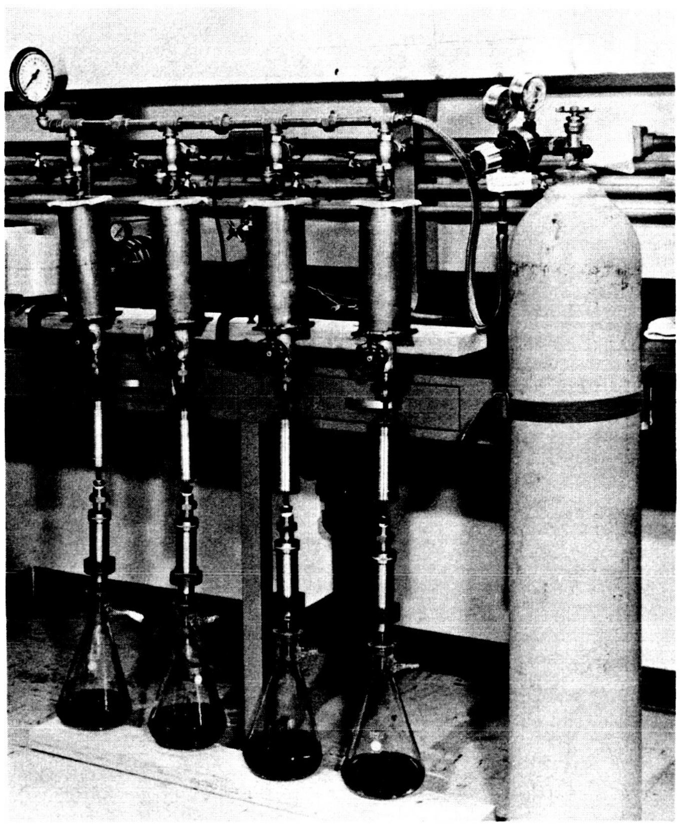

Fig. 1. Pressurized test assembly showing membrane filter holders in tandem

MICROBIAL LOAD ESTIMATION OF ELECTRONIC PIECE PARTS

NASA Work Unit 189-58-22-01-55
JPL 386-81401-2-2945

A. S. Irons

OBJECTIVE

The overall objective of this study is to determine and categorize the naturally occurring microbial flora associated with selected spacecraft parts and components for the purpose of providing necessary input for the determination of the flight acceptance cycle.

DISCUSSION

The time and temperature required to sterilize space hardware are dependent on the total microbial load associated with the hardware at the time of sterilization. Thus, the total microbial load present on all the parts of a spacecraft subsystem at the time of application of the Flight Acceptance (FA) process must be known to determine the adequacy of the cycle to produce interior sterilization. A complete examination and enumeration of the indigenous microflora of all hardware and components is not practical. It is therefore necessary to arrive at the best possible microbial load estimates by examining a selection of the parts being used to build the spacecraft. If the burden on parts is known and is considered unreasonably high, it may be possible to substitute a low-burden part for a high one. Also, it may be possible to identify the manufacturing operations which result in both "clean" and contaminated parts and make specific recommendations as to the manufacturing procedures to be used in the manufacture of parts for assembly into a capsule to be sterilized.

ACCOMPLISHMENTS TO DATE

A current 9-mo contract with Avco Space Systems Division, initiated in the first quarter of FY 1967, was primarily concerned with determining the microbial burden on selected piece parts as received from the manufacturer (see Fig. 1). In performing the initial assays, it was discovered that certain changes had to be made in the NASA Standard Procedures. The changes were mostly concerned with additional shaking and dilutions to prevent overgrowth and to permit counting (see Fig. 2) and incorporation of tests to detect bacteriostatic and bactericidal substances diffusing into the medium from imbedded parts (see Fig. 3).

A preliminary final report has been received and is being reviewed. The report contains data from the microbiological assay of twenty-two selected spacecraft parts and materials. The microbial burden (aerobic and anaerobic vegetative bacteria, fungi, and spores) on the parts was determined by assaying the parts as received directly from the manufacturer, but after a storage period of 7 days. Table 1 shows a portion of the assay data for aerobic spores. The objects assayed were electronic parts and polymeric materials used in assembly of electronic components. For each part, either 100 samples generally divided into five manufacturing lots, or 25 samples of one lot were assayed, depending on the particular part. The data obtained provided the statistical distribution of the biological burden on a particular part; and, where separate manufacturing lots were assayed, on the variation of the

burden among the separate lots. The results obtained from approximately 2200 assays are summarized and discussed in the report, as are the experimental procedures used in obtaining the data. A section of the report presents the methods used in the statistical analysis and reporting of the data. This section also contains a typical computer printout for an individual part.

The results of the study indicate a low burden on most of the parts; and, in general, electronic components were biologically cleaner than the polymeric materials. The silicone rubber and potting compounds were found to be highly contaminated.

Bacteriostasis was exhibited by only one of the parts tested for this reaction, bilaminate copper sheeting No. 26 (Fig. 3). This is to be expected because of the presence of copper which generally exhibits this phenomenon. In general, low microbial load on surfaces of electronic piece parts does not appear to be due to the presence of bacteriostatic or bactericidal compounds in the parts. Additional studies would have to be made to confirm this conclusion. Recommendations for modification of the NASA Standard Procedures for the assay of certain types of parts appear necessary and are in preparation.

PLANNED FUTURE ACTIVITIES

As a result of the information obtained regarding microbial surface load during the performance of the current contract, a follow-on contract will be issued to examine the manufacturing and handling processes of those parts found to be highly contaminated and to determine whether differences in load exist on the same type of part manufactured by different manufacturers. Studies will be conducted to determine whether or not manufacturing, handling, and screening processes can be modified to reduce the microbial surface contamination. The remainder of the contract effort will be concerned with an extensive investigation only of those parts which remain inherently highly contaminated, to determine the microbial load on such parts. The results of this contract will be used to provide information for specifications of parts which will be used on flight hardware, and to provide inputs to the load estimation necessary for establishment of subsystem FA cycles. This follow-on contract will be approximately of 11-mo duration.

It is anticipated at this time that a third contract of approximately 5-mo duration will be necessary to complete the surface load estimation of electronic piece parts and components.

PUBLICATIONS DURING REPORTING PERIOD

Contractor Reports - Interim

1. Microbiological Investigation of Selected Spacecraft Hardware and Materials, Report 6, Space Systems Division, Avco Corp., January 15, 1967 (JPL Contract 951577).

2. Report 7, February 15, 1967.

3. Report 8, March 15, 1967.

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PLANNED FUTURE ACTIVITIES

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Contractor Reports - Interim

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2. Report 7, February 15, 1967.

3. Report 8, March 15, 1967.

4. Report 9, April 15, 1967.

5. Preliminary Final Report, May 1967.

ANTICIPATED PUBLICATIONS

1. A JPL SPS article will be written upon completion of this study.

Table 1. Aerobic spore count - surfaces of selected spacecraft parts and materials

Part number[a]	Range (number of spores)	Average per surface
1	0 to 82	2.0
2	0 to 65	1.5
14	0 to 4	0.4
20	0 to 13	0.8
22	0 to 13	0.7
6	0 to 147	8.0
18	0 to 13	1.7
7	0 to 22	1.4
13	0 to 17	2.0
24	0 to 9	1.5
28	0 to 9	0.9
30	0 to 22	2.8
31	0 to 9	1.2
10	0 to 13	3.2
8	0 to 9	0.7

[a] See Fig. 1 for Part No. key.

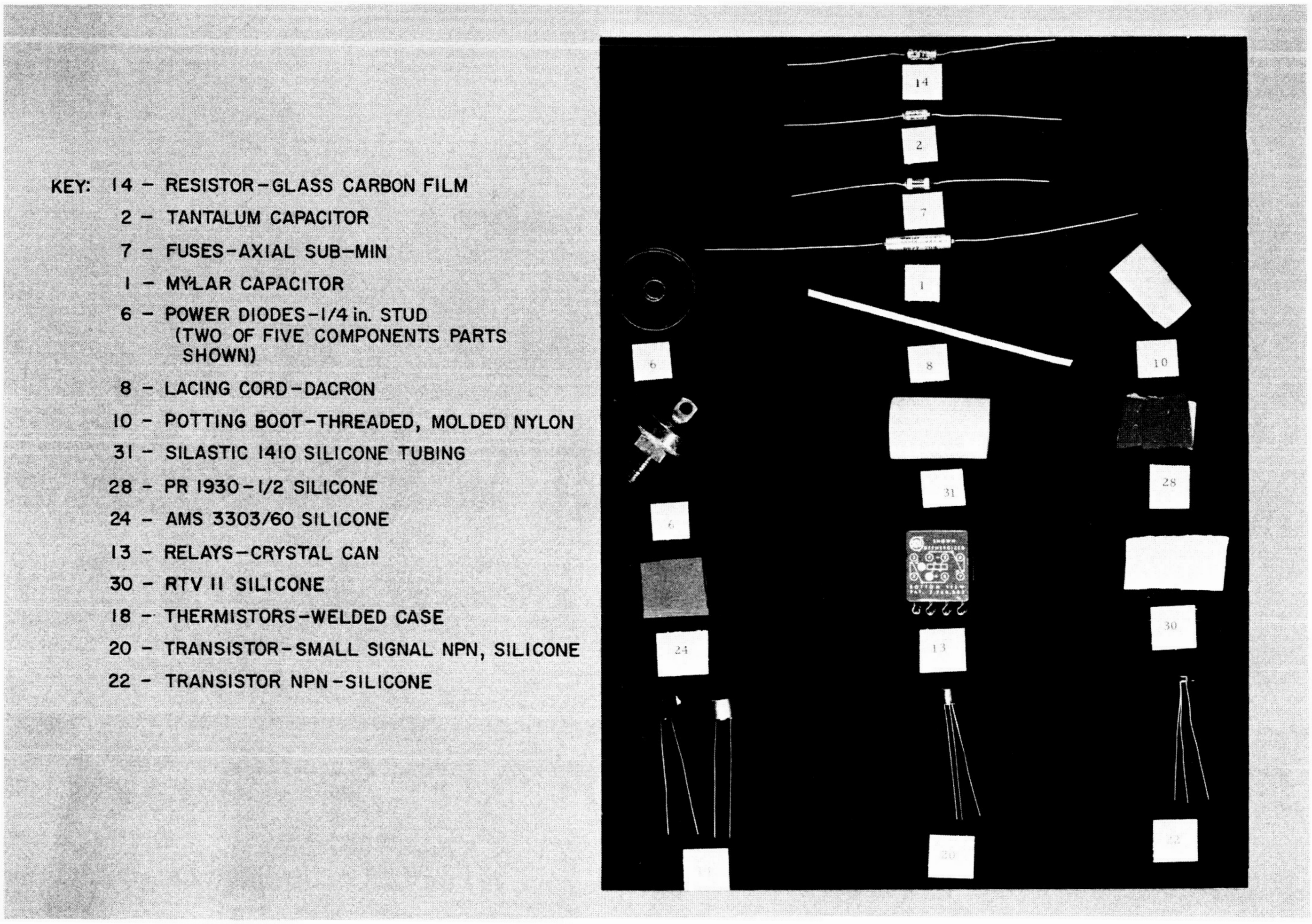

Fig. 1. Representative samples of assayed pieceparts

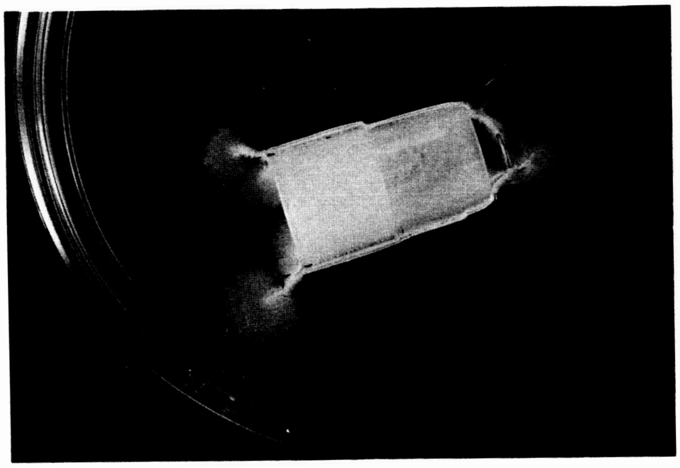

Fig. 2. Overgrowth of piecepart 10 (plated threaded potting boot, 30-h incubation at 32°C)

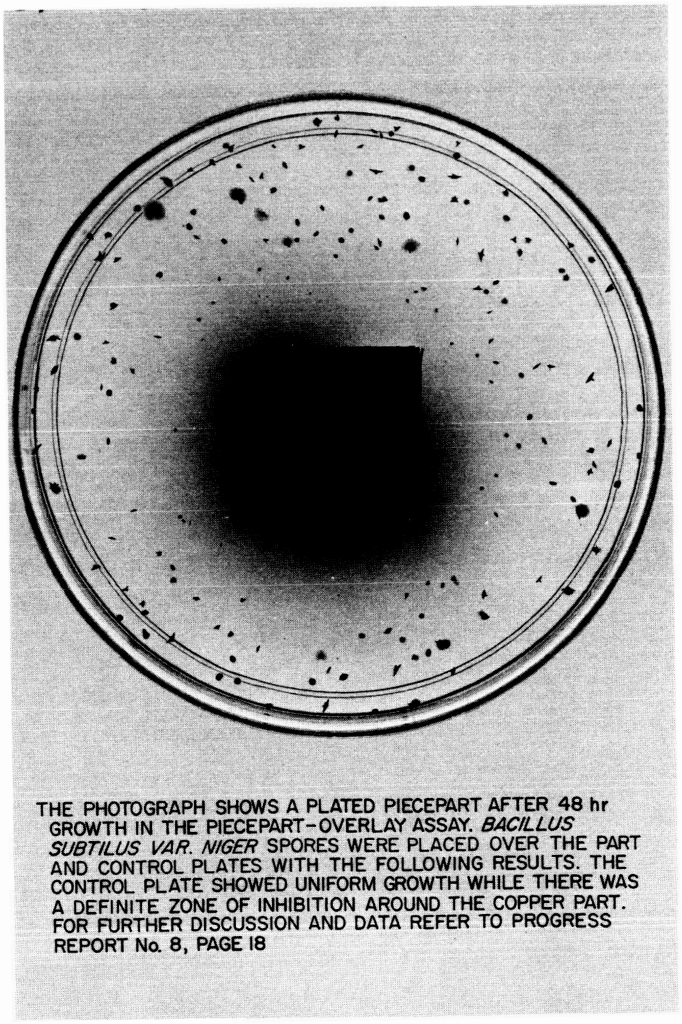

Fig. 3. Bacterial inhibition illustrated by piecepart 26

MICROBIOLOGICAL EXAMINATION OF SPACECRAFT PARTS/INTERIORS

NASA Work Unit 189-58-22-02-55
JPL 386-81901-2-2945
A. S. Irons

OBJECTIVE

The objective of this work unit is to determine the microbial load, in numbers and kinds of microorganisms, present on the interiors of electronic piece parts and components; thus, providing an input for the microbial load estimation necessary for determination of the adequacy of the flight acceptance (FA) heat test for sterilization of subsystems.

The assumption is made in calculations for determination of the terminal sterilization process that all parts interiors will be sterilized as a result of being subjected to the FA cycle, which will be more rigorous than the terminal sterilization cycle. It is necessary to determine the interior's loading to verify the adequacy of the FA cycle to achieve the required sterility.

DISCUSSION

When an attempt is made to sterilize any given material, the number of microorganisms associated with the material influences the time and temperature required to sterilize it. In order to establish an adequate sterilization cycle, it is necessary to know if viable organisms are present and, if so, how to isolate and enumerate them. Releasing organisms entrapped in a solid, or any material they are associated with, is made difficult and sometimes impossible by factors such as the bacteriostatic and bactericidal effects of the solids when placed in the recovery medium, mutilation and possible destruction of the organisms by the physical recovery technique employed, and the nutritional efficacy of the recovery-growth medium or media.

APPROACH

A previous contract with Dynamic Science Corp. demonstrated that the development of generally applicable methods for the estimation of interior microbial loads of a large number of electronic piece parts is not practical. As a result, the approach being taken at present is to review all manufacturing procedures and process data on parts to identify those parts which are subject to sterilizing time/temperature relationships during manufacture, acceptance testing, or screening. From the survey which has been completed to date, it appears that many parts receive adequate thermal exposure to kill any existing organisms. A parts list has been prepared which reflects this information. (See Table 1.)

Attention will now be directed toward an investigation of conditions occurring during manufacture and screening which will ensure internal sterility. Parts considered sterile will not be subject to further investigation. Only those considered to contain viable organisms will be used in the development of assay methods to

indicate their microbial burden. At this time we do not know the temperature or time to which most parts are exposed during manufacture. (See Table 2.)

The wide range of time and temperature to which parts are exposed during manufacture and screening indicates the need to investigate the possibility of bringing all the parts within the sterilizing range. The number of D values which must be traversed to ensure internal sterility is, of course, population-dependent; therefore, it may be necessary, in some borderline cases, to concentrate on studying manufacturing procedures to determine if cleaner methods of fabrication are called for.

ACCOMPLISHMENTS TO DATE

Prior effort in this area was concentrated on attempting to determine interior microbial burden by recovering and culturing organisms from the interiors of materials similar to those associated with spacecraft. This approach was not entirely successful. A critical review of the accomplishments indicated that the study should be redirected. Since completion of the prior "interiors" contract, in-house investigation has been concerned with studying the possibility of modifying certain manufacturing processes to produce internally sterile parts.

During the last report period funds were made available for close-out of the "Interiors Examination" contract with Dynamic Science Corp. and for preparation of a final report. During this reporting period a procurement modification was processed that established final negotiated overhead rates, provided the necessary additional costing, and extended the period of performance to permit time for preparation of the final report. The report has not yet been received.

A work statement and a procurement requisition is in process of preparation for a contract to review manufacture and screening process data. This contract will identify those types of parts which, as a result of these processes, are inherently sterile. In addition, the contract effort will evaluate recovery and assay procedures which appear most promising for the determination of interior microbiological burdens of only those specific types of parts which are inherently non-sterile.

PLANNED FUTURE ACTIVITIES

A contract will be issued in the first quarter of FY 1968 to review the manufacturing process data, to review the results of in-house investigation, to evaluate the most promising recovery and assay procedures for those parts which are not considered sterile by virtue of the manufacturing or screening procedures, and to determine if manufacturing processes can be altered to produce sterility where it does not now exist.

As a result of the review of this and the previous contract, and of similar work which has been performed elsewhere, an Interior Loading Estimation Document will be issued in FY 1968 which will provide an initial input to the microbial load estimation for FA cycle determination. An Assay Procedures Document will be issued during the third quarter of 1968, and a final Parts Interior Load Estimation Document will be issued during the second quarter of FY 1969. In addition, the results of this task will serve to provide information for the development of specifications of parts which will be used in JPL flight projects.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

Table 1. Parts list[a]

Family	Type	Specification Gen	Specification D.S.	D values traversed
Capacitors	Ceramic	ZPH-2244	0804	3.6
Capacitors	Glass	ZPH-2244	0802	71.0
Capacitors	Paper	ZPH-2244	0800	71.0
Capacitors	Tantalum	ZPH-2244	0801	71.0
Capacitors	Ceramic	ZPP-2744	2502	742.0
Capacitors	Ceramic	ZPP-2744	2503	742.0
Capacitors	Ceramic	ZPP-2744	2530	742.0
Capacitors	Ceramic	ZPP-2744	2527	742.0
Capacitors	Ceramic	ZPP-2744	2528	742.0
Capacitors	Mylar	ZPP-2744	2515	742.0
Capacitors	Mylar	ZPP-2744	2508	742.0
Capacitors	Porcelain	ZPP-2744	2511	742.0
Capacitors	Porcelain	ZPP-2744	2511	742.0
Capacitors	Porcelain	ZPP-2744	2514	742.0
Capacitors	Porcelain	ZPP-2744	2514	742.0
Capacitors	Tantalum	ZPP-2744	2501	742.0
Capacitors	Tantalum	ZPP-2744	2507	742.0
Capacitors	Tantalum	ZPP-2744	2525	742.0
Diodes	Control Rect.	ZPH-2252	all	4.2
Diodes	General	ZPH-2246	all	6.2
Diodes	General	ZPP-2746	all	0.8 to 25.0
Inductors	RF	ZPP-2738	all	2.8
Microcircuits	General	ZPP-2750	all	71.4
Resistors	Fixed	ZPP-2748	all	0.5-21
Resistors	Variable	ZPP-2749	all	N/A
Transformers	General	ZPP-2737	all	2.8
Transistors	General	ZPH-2251	all	150,000,000
Transistors	Unijunction	ZPP-2751	7037	230,000
Transistors	General	ZPP-2751	all	454 to 540
Thermistors	General	N/A	N/A	4,800,800

[a]This chart of D values traversed is based on D 125°C = 3.5 h and shows the minimum D values traversed in that it only considers sterilizing conditions imposed during screening procedures. Conditions imposed during fabrication, which may increase the number of D values traversed, have not been considered here.

Table 2. Temperatures and time durations experienced by typical spacecraft parts
D values traversed based on D 125 °C = 3.5 h

Part name and number	During manufacture		During screening		Minimum D values traversed
	Temperature, °C	Time, h	Temperature, °C	Time, h	
Capacitor ZPH-2244	not presently known		150	168	420.0
Capacitor ZPP-2744	storage at 150	168	85	168	421.0
Diodes ZPP-2746	not presently known		100	1000	22.0
Transistors ZPH-2251	storage at 200	250	100	168	50,004.0
Transformers ZPP-2737	not presently known		90	168	1.8

AUTOMATED CONTAMINATION MONITORING

NASA Work Unit 189-58-23-01-55
JPL 386-82501-2-2945

G. H. Spruce

OBJECTIVE

The objective of this task continues to be twofold: First, an investigation of presently available methods by which automatic sampling of liquids and gases may be accomplished, detecting viable (microbial) contamination with a high degree of reliability; and second, the investigation of visual monitoring systems through which an individual, remote from the critical area, can selectively monitor the activities of several, or many, workers in multiple locations, and obtain a permanent record of that which is observed.

DISCUSSION

The automatic monitoring of microbial contamination in enclosed spaces (clean rooms, glove boxes, and sterile assembly and test facilities) represents a considerable saving in time, money, and manpower. An automatic monitoring system would be invaluable in areas where the microbial load must be known at all times and where loss of sterility must be detected immediately. Currently, several devices are available which will detect, count, and automatically record particulate contamination in gases and liquids with a measurable degree of accuracy. However these devices with few exceptions such as the Anderson Sampler cannot differentiate between viable and nonviable particles.

As a part of the sterilization problem, recognizing that workers represent the least controllable source of contamination, it is necessary to develop a means of monitoring and recording all activities which may be potential sources of biological contamination.

APPROACH

A continuation of the existing survey is planned of those installations attempting (1) to automate microbiological sampling methods and (2) to reliably monitor potentially contaminating activities. After reviewing all of the available methods in both portions of the problem, a determination will be made of the susceptibility of present techniques to modification for use in the sterilization program. If not feasible, the knowledge gained in this survey will be applied to the preparation of a procurement package to develop the needed automatic sampling equipment and visual monitoring systems, respectively.

ACCOMPLISHMENTS TO DATE

As reported in the previous semiannual report, several installations have been visited in order to discuss the possibility of utilizing newly developed biological sampling devices (including those for biological warfare agents) to detect microorganisms. It appears, however, that these sampling devices are not directly applicable to our work.

Several methods of detection are under development; for example, the Sandia Corporation, Albuquerque, New Mexico, has developed a prototype sampling device for estimating total particulate contamination on surfaces; however, these devices cannot currently detect the low levels of contamination with which the sterilization task is concerned.

Work since the previous semiannual report has been restricted primarily to such visits to observe existing developmental programs as those noted above.

FUTURE ACTIVITIES PLANNED

Automated methods of sampling and assaying microbial contamination of space hardware and assembly areas will continue to be investigated as they develop, and installations developing or using such devices will be surveyed to determine the adequacy and applicability of the equipment and methods. Any applicable methods will be studied and modified as required to provide the needed automated monitoring of microbial contamination of space hardware as well as assembly/test facilities.

Visits are planned to Sandia Corporation and to Dr. Glaser of the University of California at Berkeley to examine their developments in automated monitoring devices. Dr. Lothar Salomon is reported to be working on a similar problem at Dugway, Utah; this will also be investigated.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

STERILIZATION SUPPORTING ACTIVITIES

NASA Work Unit 189-58-23-02-55
JPL 386-81101-2-2945

A. S. Irons
W. W. Paik
M. R. Christensen

OBJECTIVE

Sterilization Laboratory

The objectives of this subtask are as follows:

(1) To maintain in-house microbiological capabilities to cope with the many problems that are unique to spacecraft sterilization.

(2) To support all microbiological activities conducted by JPL in- and out-of-house, even though not directly funded by projects.

(3) To actively support the NASA sterilization program.

Microbiological Experimentation in Spacecraft Assembly Facilities

The objective of these studies is to determine the microbial populations present within environmentally controlled areas that may be used as spacecraft assembly and test areas.

DISCUSSION

NASA has assigned JPL the task of developing procedures for sterilizing space hardware. This requires definition of the problems involved and development of the methods required to solve them. In order to define and work toward the solution of the many microbiological problems associated with the sterilization of space hardware, it is and has been necessary for JPL to develop and maintain broad capabilities in the field of microbiology. The primary task of defining the problems, as well as of developing and maintaining the capabilities required to solve them, has been assigned to the Sterilization Group. Efforts to date have been concerned with:

(1) Operation of the Sterilization Laboratory.

(2) Studies designed to improve microbiological sampling and monitoring procedures.

(3) Support of project microbiological tasks.

SUBTASK I - STERILIZATION LABORATORY

Approach

The existing microbiological competency will be continued in order to support the NASA and JPL sterilization programs. Work will be continued in the Sterilization Group Microbiological Laboratory under an out-of-house contract to be issued for its management and operation. All work in the Sterilization Laboratory will be under the direction of a JPL contract monitor.

The availability of technical assistance in the preparation of sterilization documents as required, and technical and physical assistance to facilities now operating or in the process of development,will be maintained as before and increased as needed.

The laboratory will be upgraded to provide the additional incubator space and clean bench area required to take care of the increasing work load.

Accomplishments to Date

Preliminary investigative work continues to be performed under this task to define the boundaries of sterilization problems. Studies to determine the microbiological profiles of several JPL areas under various conditions of operation are being conducted on a continuing basis. Laboratory support has been provided for studies concerned with the dry heat resistance of bacterial spores associated with space hardware during assembly and test. This includes consideration of the effect of various metals, conformal coatings, potting compounds, plastics, etc., on the heat resistance of organisms.

Request for Proposal AX-3-5080 was issued to eleven qualified companies on May 5, 1967, soliciting proposals for providing personnel to manage the JPL Sterilization Laboratory for a period of one year. The proposed cost-plus-fixed-fee level of effort contract calls for the contractor to furnish a laboratory manager for approximately 2076 h, three laboratory technicians for approximately 6228 h, and one laboratory aide for approximately 2076 h. A bidders' conference was held on May 22. Five companies were represented. The deadline for receipt of bids was June 5, 1967. Three companies did not bid, six companies did not respond, and two companies made bids. The bidders were Avco Space Systems Division and McDonnell-Douglas. Evaluations are being conducted and are scheduled for completion by June 30. It is expected that this contract will be initiated approximately August 28, 1967.

The Sterilization Laboratory is still being shared with Avco personnel until the microbiological laboratory in SADL is completed.

Future Activities

Tasks to be performed by contract or JPL personnel in the JPL Sterilization Laboratory will include the following:

(1) Recovery, identification, and heat-resistance studies on microbial isolates from space hardware.

(2) Evaluation of factors influencing dry-heat resistance of spores.

(3) Support of JPL facilities in all microbiological activities as required.

(4) Provide information relative to the sterilization program and consultation as the need arises.

(5) Revision and updating of procedures and techniques as required.

(6) Procurement of equipment and supplies as needed to provide for the maintenance and updating of equipment and the existing facilities.

SUBTASK II - MICROBIOLOGICAL EXPERIMENTATION IN SPACECRAFT ASSEMBLY FACILITIES

Approach

The microbiological techniques utilized for air and surface sampling have been previously described (JPL SPS 34-37, Vol. IV, August 31, 1965).

Accomplishments

The microbiological profiles of various JPL and Cape Kennedy assembly and test facilities were established. These included:

(1) The Environmental Test Laboratory - JPL Bldg. 144.

(2) Spacecraft Assembly Facility - JPL Bldg. 179.

(3) Space Simulator Chamber - JPL Bldg. 244.

(4) Hanger AO - Cape Kennedy.

(5) Explosive Safe Area - Cape Kennedy.

These studies were conducted in conjunction with "Microbiological Monitoring of Spacecraft Assembly Facilities."

Planned Future Activities

It is anticipated that those facilities which may in the future be utilized for spacecraft assembly and test operations will be microbiologically evaluated. Studies will also be conducted to determine the effectiveness of using "clean rooms" for future spacecraft assemblies.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Paik, William W., Christensen, Marvin, and Stern, Joseph A., "A Microbiological Survey on Environmentally Controlled Areas," SPS 37-41, Vol. IV.

MICROBIOLOGICAL MONITORING OF SPACECRAFT ASSEMBLY FACILITY OPERATIONS

NASA Work Unit 189-58-23-03-55
JPL 386-80401-2-2945

M. R. Christensen
R. H. Green

OBJECTIVE

The objective of this work unit is to obtain experimental estimates of the microbial and particulate contamination associated with the assembly and testing of spacecraft.

DISCUSSION

Microbiological monitoring of various spacecraft assembly facilities was continued in an effort to determine the microbial and particulate contamination levels associated with various degrees of personnel activity.

In addition, the microbiological monitoring program conducted on the Mariner Venus 1967 spacecraft was successfully culminated. This program offered a unique opportunity to develop and test techniques for assessment of the microbial loading which accumulates on spacecraft surfaces during assembly, test and prelaunch operations.

APPROACH

The program approach incorporated standard state-of-the-art techniques, as well as various improvisations developed for the task. Airborne particulate monitoring was conducted using a Royco Particle Counter, and microbial airborne contamination levels were assessed by means of Reyniers air samplers. Handling and contact contamination levels were measured by use of Rodac Contact plates, swab techniques, and stainless steel settling strips. The stainless steel strips used to monitor the Mariner V spacecraft were contained in aluminum holders carried between nine to fifteen 1-in.-square strips. Each holder was portable, self-enclosed, and sterilizable. The units were attached to the spacecraft or its support equipment by a Mariner Development Section representative. Spacecraft sampling areas include the top ring (Fig. 1a) and the outer face of seven electronic bays (Fig. 2a). Other holders were attached to ground support equipment such as the attitude gas control handling frames (Fig. 2b) and the spacecraft support ring (holders not shown). By placing the holders in these locations, both horizontal and vertical surfaces were represented. Whenever spacecraft operations necessitated removal of the holders, they were transferred to a model (Fig. 3) and maintained in their proper relationships until reattachment to the spacecraft was feasible.

During transportation of the spacecraft from Pasadena to Cape Kennedy, the strips were maintained in special holders which permitted direct attachment to the spacecraft corner brackets (Fig. 2c). This arrangement allowed monitoring of the environment of the shipment cannister during transit.

Strips were removed at weekly intervals and assayed for microbial accumulation according to methods presented in NASA Standard Procedures for the Microbiological Examination of Space Hardware, June 1, 1966. Contamination levels were calculated per square foot of surface.

Swab samples were also obtained on a weekly basis from specific locations on the spacecraft (Fig. 4). Individual samples (4 in.^{2}) were taken from the electronic chassis, the attitude gas control handling frames, pressure switches, umbilical junction, postinjection propulsion system, and select instrumentation, such as the Canopus sensor, the low-gain antenna, high-gain antenna superstructure, ultraviolet photometer, secondary sun sensors, and the struts of the solar panels. Contamination levels were calculated per 4 in.^{2} of surface.

Pertinent information was obtained which is directly applicable to future studies, such as the assembly and testing of Mariner Venus 1969, where the validity of the developed techniques will be tested. Further revisions and refinements of these techniques will be implemented during this period, and the resulting program will be available for application to a Voyager-type spacecraft.

ACCOMPLISHMENTS TO DATE

Microbiological profiles were obtained from fallout data obtained from the JPL Spacecraft Assembly Facility (JPL Bldg. 179), Vibration Test Area (JPL Bldg. 144), and the Space Simulator Chamber (JPL Bldg. 248), as well as the JPL clean room (Hangar AO) and the Explosive Safe Facility (Area 60) at Cape Kennedy.

In conjunction with this the spacecraft monitoring program began December 27, 1966, and was culminated just before encapsulation on May 28, 1967, sixteen days prior to launch. During this period, spacecraft surfaces were monitored for the microbial contamination which accumulated during assembly, test, shipment, verification, loading, and prelaunch operations. Tables 1 and 2 represent surface microbial burden estimates on the Mariner V spacecraft using the settling strip and swab techniques. These calculations are based on the assumption that the total exposed surface area on the spacecraft is approximately 645 ft^2. The highest spore estimate obtained using the strip technique indicates 3.3×10^5 spores/spacecraft as opposed to 3.7×10^4 spores/spacecraft using the swab method. Data obtained on May 28, 1967 from the spacecraft, adaptor, and shroud was utilized to verify compliance to a NASA Planetary Quarantine Office directive.

PLANNED ACTIVITIES

Data received from the program has been compiled and is currently being analyzed to determine microbial burden on the spacecraft as related to personnel activity and specific spacecraft operations. Additionally an analysis of variance between samples is being conducted to determine the distribution of microorganisms on the spacecraft. After statistical analysis the resultant information will be used to develop the microbiological sampling programs for future flight projects.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Christensen, M. R., Stern, J. A., and Green, R. H., "Microbiological Sampling Program, Mariner 1967," SPS Vol. IV, July 1967.

Table 1. Settling strips, microbial burden estimates[a]

Month	Aerobic shock	Aerobic Δ shock (spores)	Anaerobic	Anaerobic Δ shock (spores)
Feb.	3.7×10^6	3.0×10^5	1.3×10^4	3.2×10^4
Mar.	1.8×10^6	3.2×10^4	1.3×10^5	6.4×10^4
Apr.	1.8×10^6	3.3×10^5	3.2×10^5	1.2×10^5
May	6.5×10^6	1.8×10^5	4.3×10^6	8.4×10^4

[a]Assuming 645 ft^2 of exposed surface area.

Table 2. Swab data microbial burden estimates[a]

Month[b]	Aerobic	Aerobic Δ shock (spores)	Anaerobic	Anaerobic Δ shock (spores)
Feb.	3.0×10^4	8.4×10^3	8.4×10^3	6.4×10^2
Mar.	7.2×10^4	2.1×10^4	1.0×10^4	2.6×10^3
Apr.	2.8×10^5	3.7×10^4	5.0×10^4	1.3×10^3
May	9.9×10^5	2.3×10^4	2.4×10^4	6.4×10^3

[a]Assuming 645 ft^2 of exposed surface area.

[b]Average of weekly samples.

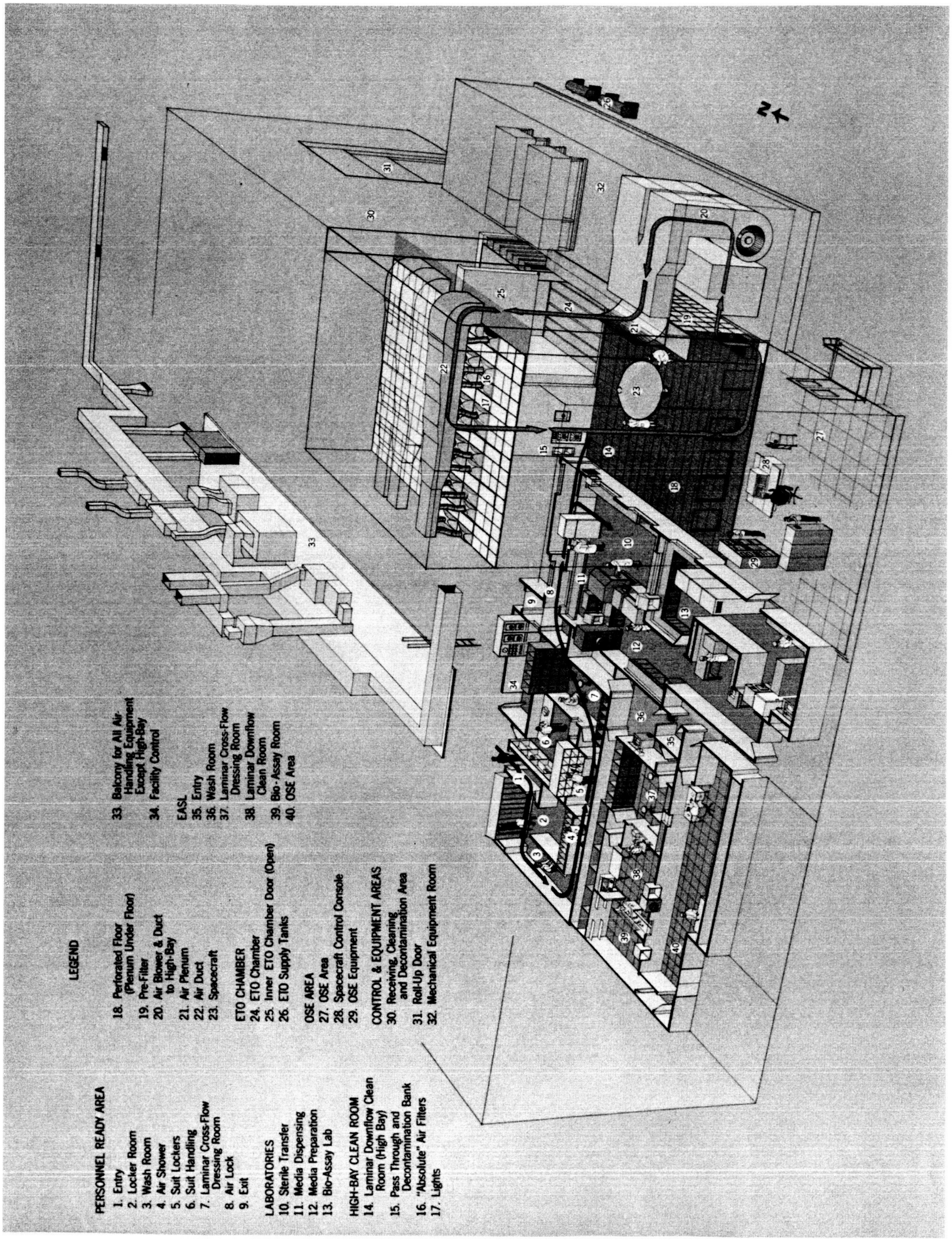

Fig. 1. EASL/SADL facilities

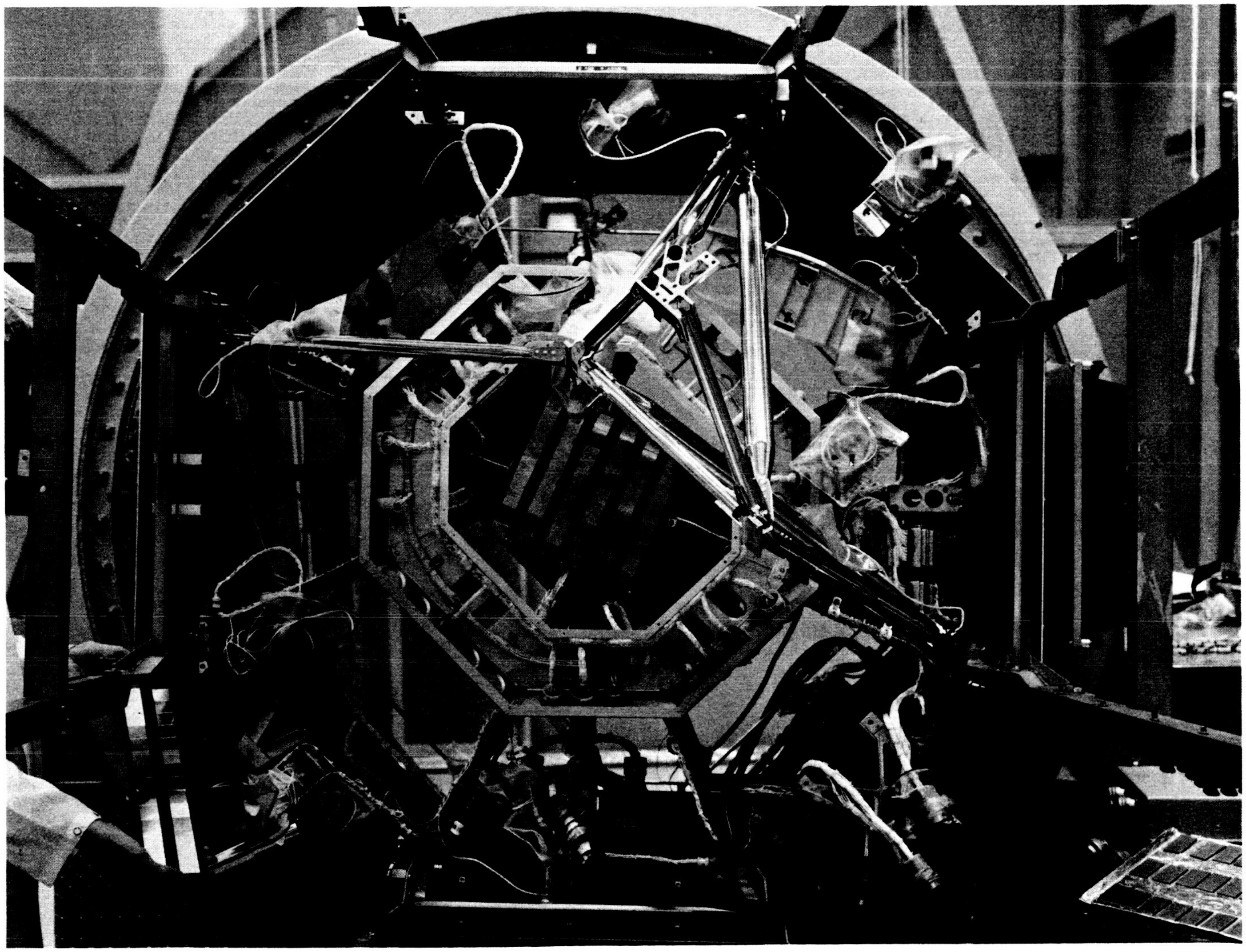

Fig. 2a. Location of settling strips on MV V top ring structure

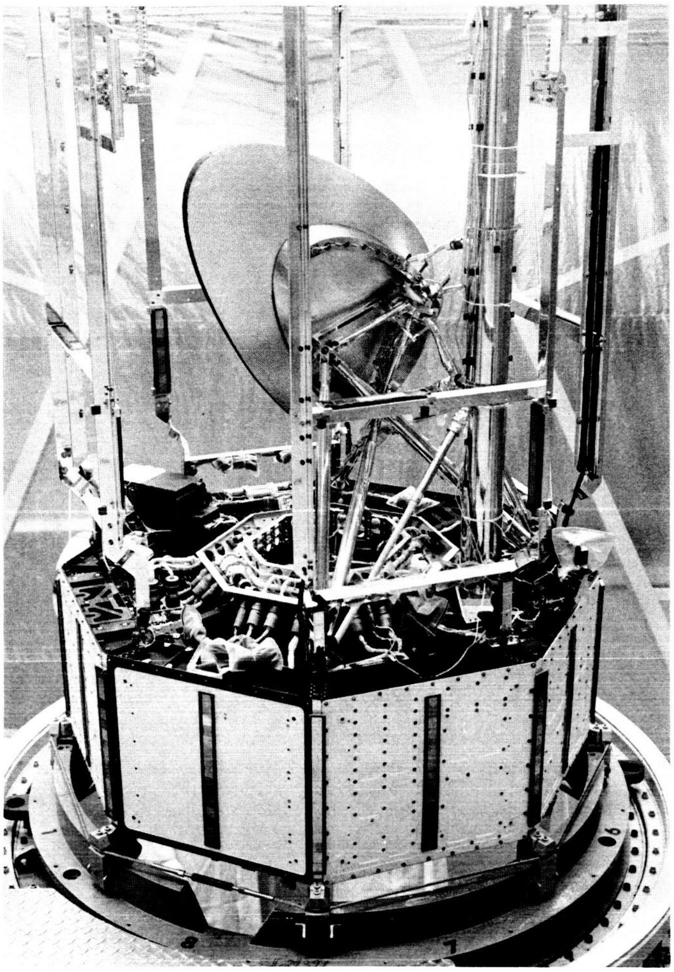

Fig. 2b. Location of settling strips in the electronic bays support ring and corner brackets of MV V spacecraft

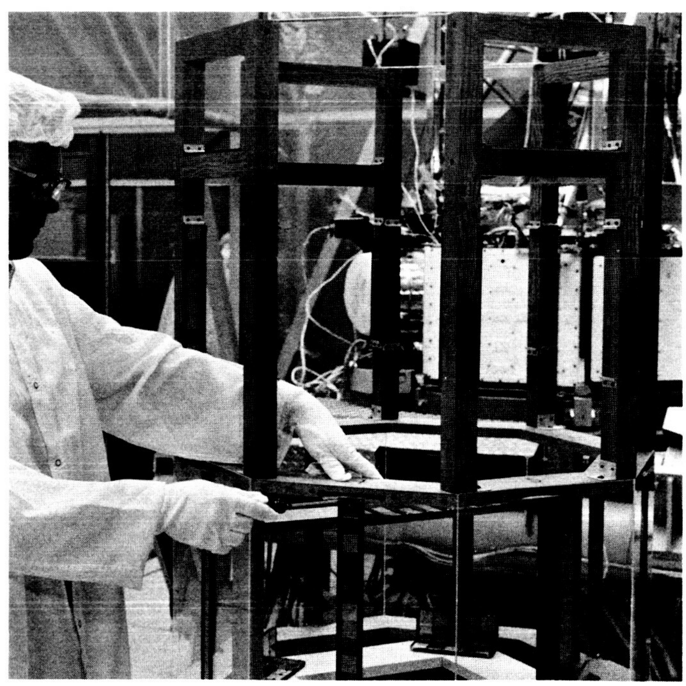

Fig. 3. Model for settling strips attachment during periods when testing required removal from spacecraft

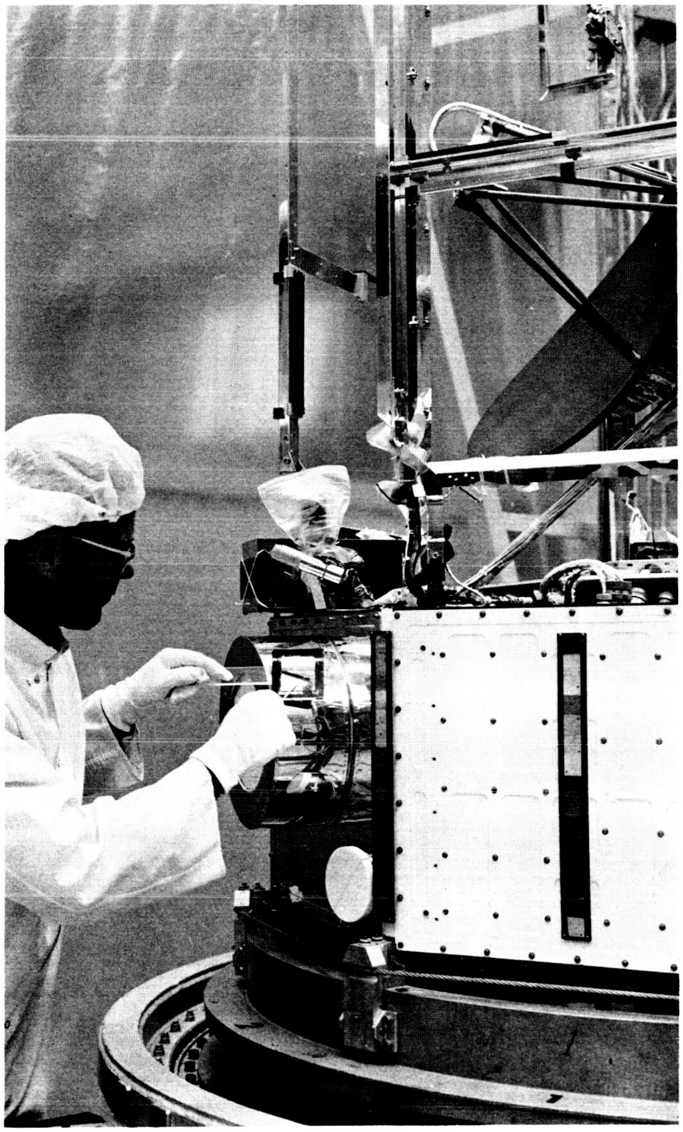

Fig. 4. Method used for collection of swab samples from spacecraft

EASL/SADL TEST AND OPERATIONS

NASA Work Unit 189-58-23-04-55
JPL 386-80501-2-2930
G. H. Redmann

OBJECTIVE

The objectives of EASL/SADL Test and Operations are as follows:

(1) Develop and optimize the techniques and specify the minimum equipment and facilities necessary to assemble, test, encapsulate, and sterilize a capsule in accordance with reliability requirements while constrained by the planetary quarantine requirements.

(2) Develop, demonstrate, and specify the techniques, equipment, and facilities necessary to certify that a capsule has met the planetary quarantine requirements.

DISCUSSION

The work is being performed on a task system basis by a contractor, the Avco Corporation, Lowell, Massachusetts under JPL Contract 951624. Phase I of the EASL/SADL Test and Operations contract was awarded in September 1966, and was completed on April 1, 1967. Phase II is currently under contract and terminates on August 15, 1967. The facilities in which this work is being performed are the Experimental Assembly Sterilization Laboratory (EASL) which contains a 400 ft^2, class 100, laminar downflow clean room with supporting equipment, and the Sterilization Assembly Development Laboratory (SADL) which contains a 1200 ft^2, class 100, laminar downflow clean room with supporting equipment and a complete microbiology lab. Construction of the SADL facility has been completed with the exception of several items of collateral equipment which have yet to be installed. (Figure 1 shows the EASL/SADL facilities.) The ETO chamber and the terminal sterilization chamber are under construction and will be ready for phase III operations.

A 14-ft-diam Capsule Mechanical Training Model (CMTM) consisting of a Mariner C type of bus, eight Ranger-series electronic modules, a deorbit motor, a 4-ft-diam impact limiter, a relay antenna system, and an aeroshell are the hardware used to develop the various sterilization assembly procedures.

Phase I consisted of contractor orientation and training in EASL operating procedures. Phase II consists of tasks related to the checkout and evaluation of SADL and placing the facility into operational readiness. Phase III will consist of the actual operation of SADL and in performing decontamination, assembly assay, simulated system testing, and terminal sterilization of the CMTM.

ACTIVITIES DURING REPORT PERIOD

Phase I which was concluded on April 1, 1967 consisted of the following tasks:

(1) Review and revise existing EASL operations documents and convert for use in SADL.

(2) Prepare and implement a SADL certification plan.

(3) Prepare SADL operations handbook and inventory lists.

(4) Prepare a quality assurance program plan for EASL and SADL using applicable portions of NASA Document NPC 200-2.

(5) Develop and document the techniques, procedures, alignment checks, and simulated system tests for a prototype capsule system assembly.

(6) Fabricate electronic subassemblies in EASL to optimize facility and hardware operations/procedures.

(7) Perform microbiology tasks as follows:

  (a) Evaluation of the microbial contamination on typical subsystems.

  (b) Evaluation of the NASA Standard Sampling Procedures.

  (c) Personnel clothing study.

  (d) Identification of microbial isolates from the EASL.

  (e) Determination of the heat resistance of the microbial isolates from the EASL.

  (f) Study of the plateau of microbial contamination on surfaces.

  (g) Study of chemical germicide.

  (h) Contamination analysis and monitoring procedure tests.

The results of this work included test plans and procedures contained in the reports listed under "Publications During Report Period".

Phase II which is now in progress consists of the following items of work:

(1) Certify the SADL facility and ancilliary equipments.

(2) Conduct a formal training program for personnel required to enter SADL.

(3) Assemble and disassemble Capsule Mechanical Training Model according to procedures developed in phase I, and prepare the CMTM subsystems for entry into the SADL bio clean room (phase III).

(4) Prepare a monitoring plan for installing bio-coupons, ETO, and temperature indicators.

(5) Implement and revise as necessary the quality assurance plan developed in phase I, and develop specifications, techniques, and procedures for operations in the SADL facility.

(6) Prepare procurement requisitions for JPL approval for equipment and supplies for the SADL operation.

(7) Prepare SADL facility equipment and maintenance procedures and provide engineering liaison support for equipment and facility modifications.

(8) Develop an assay plan structured for eventual microbiological certification of SADL.

(9) Develop and document techniques, procedures, and plans necessary to estimate the microbial load upon the CMTM assembly.

(10) Operate the EASL facility in support of sterilization tasks and develop procedures to minimize contamination.

(11) Study the effects of varying established operating and maintenance procedures and contamination controls in EASL.

(12) Develop a math model for use with the CMTM which represents the expected microbial load and predicts the changes thereto as a result of assembly and testing operations.

A Work Statement for phase III has been completed and negotiations for this phase of the work are in progress.

PUBLICATIONS DURING REPORT PERIOD

Contractor Reports

The following reports were prepared by the Avco Corporation under JPL Contract 951624 covering the work performed in phase I:

1. Quality Assurance Program Plan - SADL, Report 67-103.

2. Sterilization Assembly Development Laboratory Certification Plan, Report 67-104.

3. Evaluation of Prelim. Standard Proced. for Micro. Exam of Space Hardware, Report 67-105.

4. Operations Handbook - SADL, Report 67-106.

5. Operations Handbook - EASL, Report 67-107.

6. Clothing Study - EASL, Report 67-108.

7. CMTM - Assembly/Disassembly Log, Report 67-109.

8. Decontamination of Tools & Equip. for Assem./Disassem. of CMTM in SADL, Report 67-110.

9. Inventory List - EASL, Report 67-111.

10. Inventory List - SADL, Report 67-112.

11. Report on a Study of Chemical Germicides, Report 67-113.

12. Report on Study of Plateau of Microbiological Contamination on Surfaces, Report 67-114.

13. Identification of Microbiological Isolates - EASL, Report 67-115.

14. Report on Determination of Heat Resistance of Microbiological Isolates, Report 67-116.

15. Report on Effectiveness of Utilizing Assay Coupons for Biol. Load Prediction, Report 67-117.

16. CMTM - Assembly & Simulates Test Procedure, Report 100.00.

17. Process Spec., Decontamination of Component Parts, Tools & Equipment, Report 200.01.

18. Personnel Procedures for SADL Operations, Report 201.00.

19. Personnel Procedures for EASL Operations, Report 201.01.

20. Routine Cleaning & Decontamination of SADL Facility, Report 202.00.

21. Routine Cleaning & Decontamination, Report 202.01.

22. Microbiological Assay & Certification of Spacecraft Hardware Sterility, Report 300.01.

ANTICIPATED PUBLICATIONS

1. Contractor reports covering all work performed in phase II.

AUTOMATED BIOLOGICAL LABORATORY (189-73)

AUTOMATED BIOLOGICAL LABORATORY
NASA Work Unit 189-73-01-01-55
JPL 360-311xx-2-32xx
H. W. Ford
G. M. Hotz
R. F. Rice

OBJECTIVE

The objective of this task is to generate the science requirements for the biological exploration of Mars. Short-range objectives are as follows:

(1) Conduct an Automated Biological Laboratory (ABL) study which will establish a scientific strategy for the biological exploration of Mars, a logical sequence of missions to accomplish the scientific objectives, and a definition of the evolutionary series of science systems which implement the mission objectives.

(2) Identify and pursue the development of sample acquisition, transport, and processing techniques which will be required for the anticipated array of science instruments.

(3) Identify the areas of technology in control and data handling which will require special development if the defined missions are to be carried out.

ABL STUDY (360-31101-2-3200)

Objective

The immediate objective of this study is to prepare a report on a plan for the first three missions in the biological exploration of Mars. The report is to consist of three sections: (1) The Science Rationale, (2) The Mission Science Program, and (3) The Mission Science Design Requirements.

Progress

The study leading to the first iteration of the report has been completed and the first section published on March 30, 1967. The studies for the remaining two sections have been completed and are in final draft; they will be distributed before August 1, 1967.

ABL INSTRUMENTS (SAMPLING) (360-31102-2-3220)

Objective

The objective of this program is to develop information which will lead to the design of devices capable of supplying uncontaminated and unaltered biological samples of planetary surface materials to instruments aboard a landed vehicle.

Out-of-House Sampler Development

Figure 1 is a listing of both geological and biological samplers currently under development in- and out-of-house. Samplers N. 3 and 9 of Fig. 1 were developed under Contract NASw-1065 Mod 2 by the Philco-Ford Corp., Space and Re-Entry Systems Division, Newport Beach, California.

The contract was completed February 17, 1967 with the development, debugging, and testing of the vertically deployed conical abrasive sieve prototype sampler (Fig. 2) and the construction only of the horizontally deployed rotating wire brush telescoping boom prototype sampler (Fig. 3). Contract funds ran out before the horizontal sampler could be made to operate, but some estimate of its expected performance may be inferred from tests run on the breadboard model of this sampler previously described. Additional development of this sampler is contemplated in FY 1968 (see Future Activities). The final report, Publication 1, describes the effort in detail. In addition to the two samplers which were produced, the following work was accomplished:

(1) Conceptual design studies of ABL precursor samplers.

(2) Parametric design studies of sampler deployable booms.

(3) Parametric design studies of pneumatic motors and compressors.

(4) Production of required soil models and rotating soil bins.

(5) Aerosol transport tests to permit extrapolation of earth ambient tests to Martian ambient conditions for the flow geometry within the horizontal samplers boom.

(6) Parametic configuration testing of the wire brush breadboard sampler.

In-house Sampler Development

The bulk of the in-house work accomplished during this reporting period has been on a series of geo-bio samplers and sampler components in conjunction with the Geosampling task intended:

(1) To provide subsurface samples from various depths without undue mixing with material from other depths. Such samplers could provide relatively uncontaminated samples in a retro-rocket affected area.

(2) To provide bulk samples from the near subsurface. Such mechanical samples will acquire larger particulates than aerosol (Litton type) samplers or other selective particulate samplers.

(3) To transport particulate through high-pressure aerosol streams to increase transport distance over that obtainable through ambient pressure aerosol (Litton type) transport.

Figure 4 shows a breadboard of a deep subsurface version of the abrading-sieve-cone type at the other end of the depth spectrum from the Philco-Ford vertical sampler which is intended to enter the soil only about an inch. It penetrates about

2 ft into sand or rubble soil models and collects about 500 g of sample in 30 min. The sample is continuously transported up from the cone through the drive tube by means of an internal screw conveyor and will supply stratographic information, if desired, with about 5% mixing between layers 4 in. apart. Wearing of the silicon rubber liner of the screw conveyor causes about 0.025% contamination of the sample with carbon, which would be incompatible with some biological experiments. The use of other elastomeric or metal liners is being investigated.

The drive tube and acquisition head assembly of this breadboard was made removable to allow for the breadboarding of other sampling concepts on this same rig. Two other concepts have been fabricated and are ready to be tested. One has a rotary drill tip on the end of the drive tube with screw sample transport up the tube. The other concept places the drill tip on the end of the screw transport shaft and the drive tube simply becomes a non-rotating casing.

A soil auger breadboard sampler has been designed and is being fabricated (see Fig. 5). It will serve as a large-capacity near-subsurface bulk sampler.

Figure 6 shows a variation of the abrading cylindrical particulate sampler reported on in the previous semiannual report. This sampler uses a closed high-pressure gas transport system which operates independently of the ambient atmosphere (such as lunar vacuum) and can convey the sample considerable distances. Possible transport ranges appear to be as great as 1000 ft through 3/16-in. -10 tubing and 500 ft through 1/8-in. -10 tubing.

Some work has also been accomplished on a centrifugal blower which could replace the (Litton type) air ejector in missions where the emission of foreign gases (from earth) might be objectionable and the weight and complexity of a compressor to provide high-pressure Martian gas are not permissible.

Future Activities

A follow-on JPL contract (951935) is being negotiated with Philco-Ford to provide more extensive laboratory testing of the two samplers developed on Contract NASw-1065 Mod 2 in more soil models including biological models, layered models, and rock models. These tests will also include the influence of surface slope and texture, Martian atmosphere, and wind. Field testing in multiple models in one or two general desert sites is also contemplated. Biological testing will be conducted in biological soil models in the laboratory and in field models. The contract will also include:

(1) Evaluation tests of approximately five JPL geo-bio samplers in natural field environments (program 185 funding). This task will be performed in conjunction with field testing of the Philco-Ford samplers and will include biological evaluations.

(2) Research and analyses to determine the feasibility of the passive sampler (i.e., one which collects wind-borne material utilizing the energy of the wind rather than Surface-Laboratory-supplied energy).

This contract will be monitored on Voyager SLS funding as will future in-house sampling efforts (other than Geosampling).

A milestone chart indicating the schedule established for this work unit is shown in Fig. 7.

CONTROL AND DATA HANDLING (360-31103-2-3240)

Objective

The objectives of this program are:

(1) To provide support to the VBL Study Committee in the area of data systems.

(2) To identify possible scientific payloads and gather functional descriptions of control and data handling characteristics of the possible instruments associated with a VBL.

(3) To study the control and data characteristics of each instrument for the purpose of identifying areas of technology which will require special developments.

Progress

At various times, the Study Committee has called upon the Advanced Science Data Handling Group for assistance.

This assistance has been supplied in various proportions by personnel in the group specializing in the specific problem area. This was especially true in regard to a study which generated a set of functional specifications for a 1973 mission for the purpose of estimating the size and complexity of a science data subsystem for such a payload.

The statement "identify possible scientific payloads" should be described more fully.

A specific definition of "what is a VBL" is still as yet a very much debated question. The VBL study committee is attempting to answer these questions.

We can at least say, however, that a VBL should be capable of establishing the state of biological evolution of Mars. We can also say that it will evolve out of or as part of the Voyager Program.

However, at this time, a description of a VBL payload (i. e., complete instrument complement) is only conjecture. This is especially true in identifying instruments which are directly involved with biology.

A significant result of the proceedings of the VBL study committee was the conclusion "that if life exists on Mars, it will seek out ecological niches, and that in such niches, population densities may be many orders of magnitude higher than the density averaged over the surface of the planet." A conclusion then is that to maximize the detection of life, the VBL will be required to seek out these niches. Seeking these niches will of necessity require instruments which cannot in themselves derive results which are conclusive of life but which can direct us to more probably locations. For instance, the detection of organic material in some areas might tell us to

activate our specific life detection equipment. Similarly, optical imaging might tell us in what general direction to go - or to look under a rock or to merely avoid obstacles.

Therefore, the identifications of "possible scientific payloads" under item (2) above have been primarily concerned with identifying instruments in this category. A notebook entitled "Instrument Data Sketches" was compiled and will be continually augmented. The notebook contains a functional description and data characterization of instruments which may be a part of a VBL's life-seeking equipment and other instruments (not necessarily VBL) which have similar data characteristics or functional operation.

Since the purpose of this notebook is to identify problems which might require special study and the fact that some instruments do not have any definitive specifications (Gas-Chromatograph/Mass Spectrometer, for example), the descriptions are not number-oriented but instead concentrate on identifying the magnitude of control and data handling problems (on-board processing, for example).

Two studies resulted from this sketch book: (1) A study of the data characteristics of a low-energy particle detector may result in reduced memory requirements for an alpha-scattering equipment which may be a supplementary experiment on a VBL. (2) The development of techniques for statistical data compression of a mass spectrometer output should be quite useful in the more advanced VBL type missions. A report describing the results of the latter is presently in preparation.

Future Plans

Support of the VBL committee will continue in its present mode. Continued collection of instrumentation data will orient itself more towards the biological. This will become possible as the concepts developed by the committee permit a better extrapolation into the future.

PUBLICATIONS DURING REPORT PERIOD

Contractor Reports, Interim and Final

1. Automated Biological Laboratory Soil Sampling Study, Report UG-3962, Philco-Ford Space and Re-Entry Systems Division, February 17, 1967.

ANTICIPATED PUBLICATIONS

None.

SAMPLER		BREADBOARD STATUS			ORDER OF COMPLEXITY	USE	
		DESIGN	BUILT	TESTED		GEO	BIO
HARD ROCK SAMPLERS	1. UNCASED DRILL (HTC)				4	√√	—
	2. CASED DRILL (JPL)	(BEING REDESIGNED)			5	√√	—
SELECTIVE PARTICULATE SAMPLERS	3. SHALLOW ABRADING SIEVE CONE (PHILCO-FORD)				3	√√	√√
	4. DEEP ABRADING SIEVE CONE (JPL)				3	√√	√
	5. ROTATING DRUM SIEVE (JPL)				2	√√	√√
	6. HELICAL CONVEYOR-DRILL TIP (JPL)				2	√√	√√
	7. HELICAL CONVEYOR-PLAIN TIP (JPL)				1	√√	√
	8. AEROSOL ACQUISITION (LITTON)				2	—	√√
	9. ROTATING WIRE BRUSH (PHILCO-FORD)				5	√	√√
	10. ROTATING BATCH DRUM SIEVE (JPL)				3	√√	√√
BULK PARTICULATE SAMPLERS	11. AUGER (JPL)				3	√√	√√
	12. BACKHOE (HAC/JPL)	(TO BE REDESIGNED)			5	√√	√√
	13. DRAGLINE SCOOP (JPL)				2	√	√√

1 SIMPLE
5 COMPLEX
√√ GOOD
√ FAIR
— POOR

Fig. 1. Development status of sampler breadboards

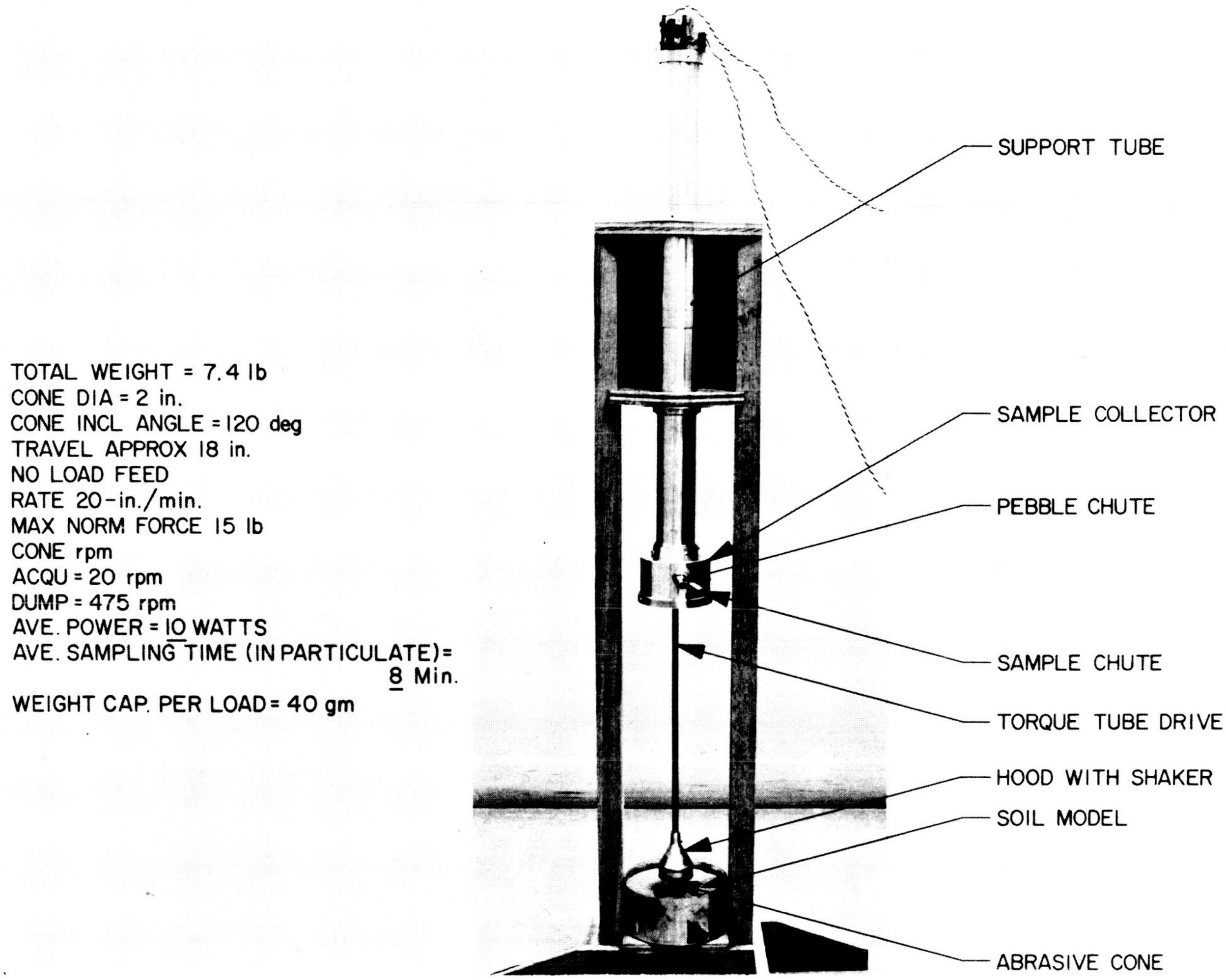

Fig. 2. Philco-Ford vertically deployed conical abrasive sieve

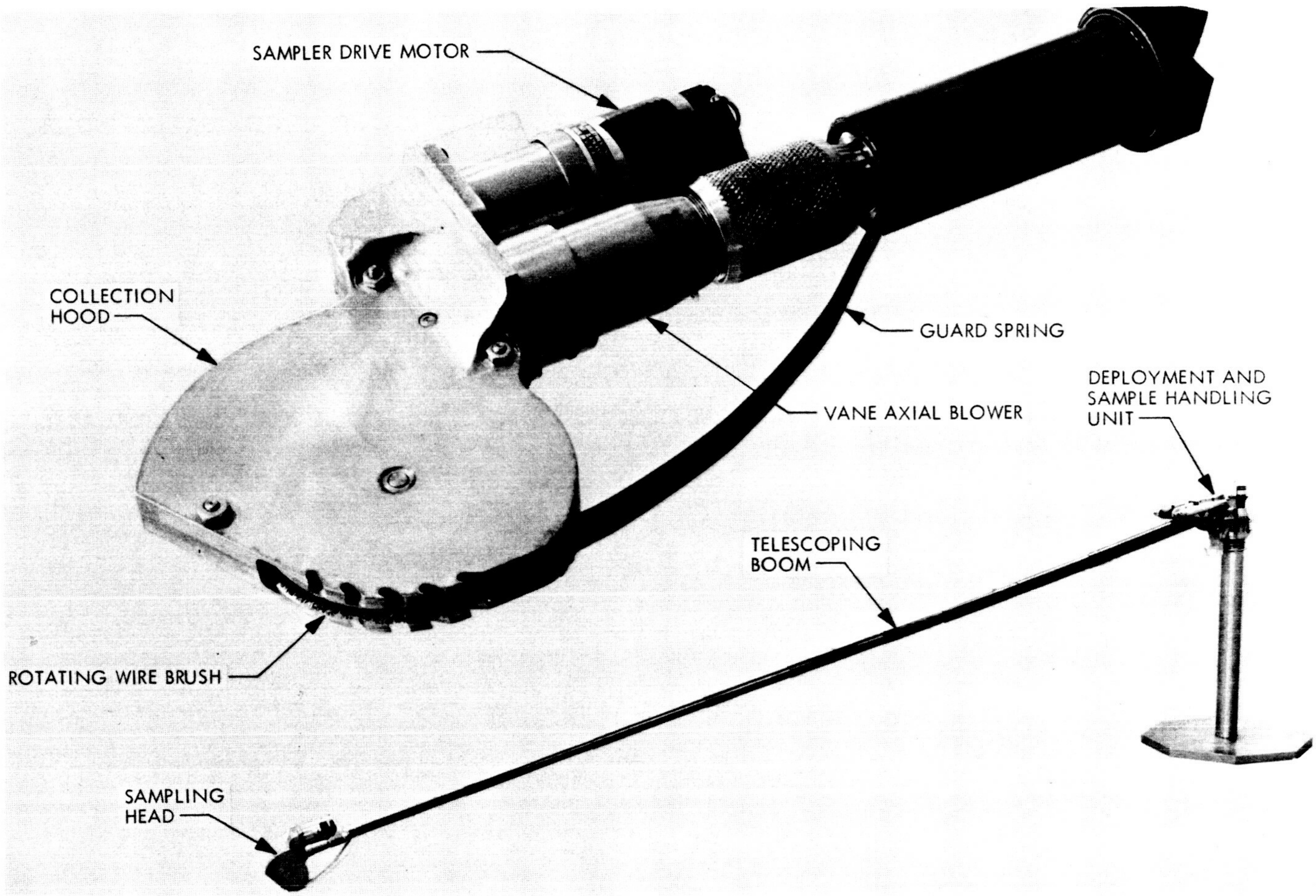

Fig. 3. Philco-Ford rotating wire brush telescoping boom sampler

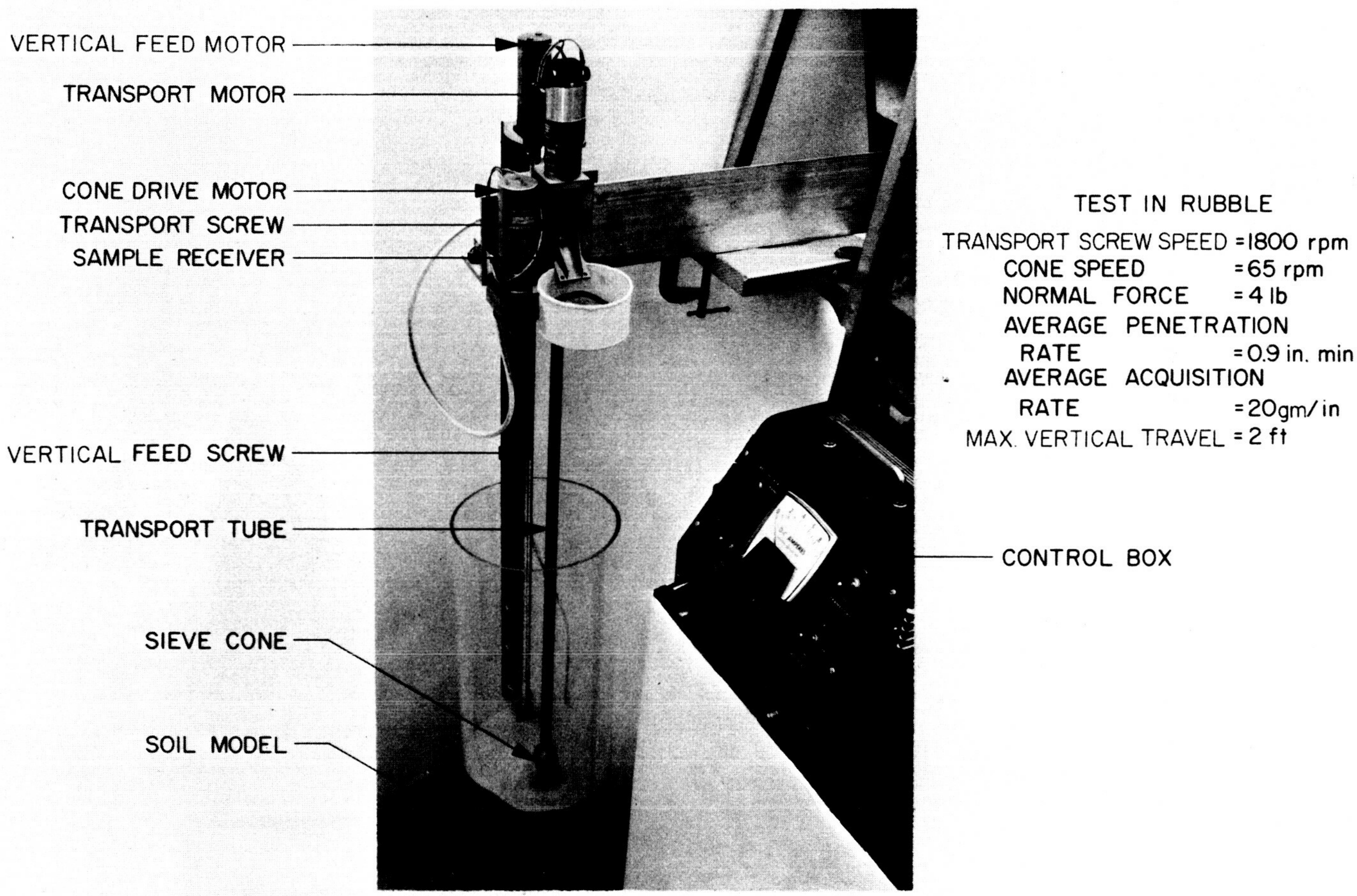

Fig. 4. Deep subsurface sieve cone sampler

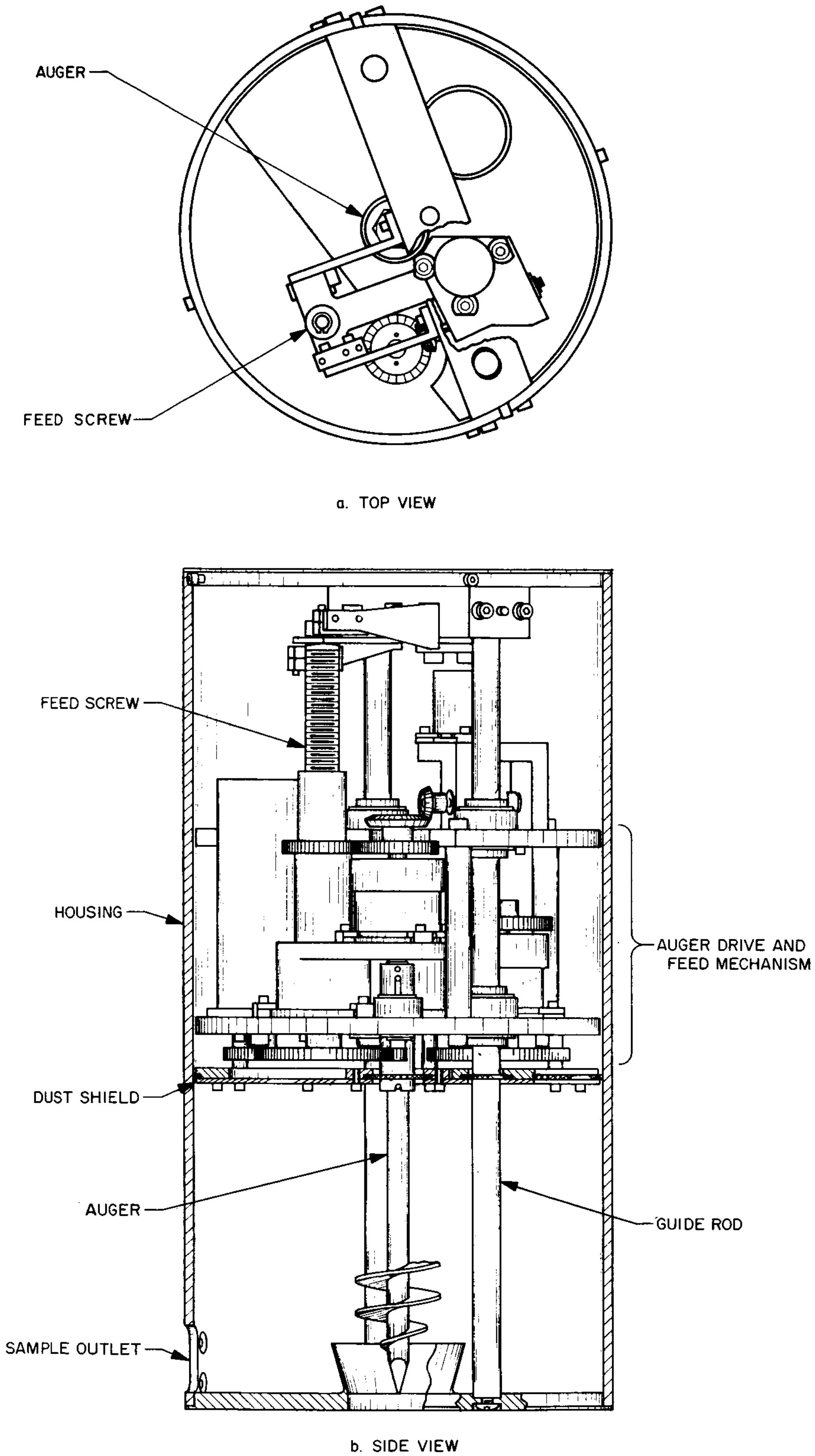

Fig. 5. Soil auger

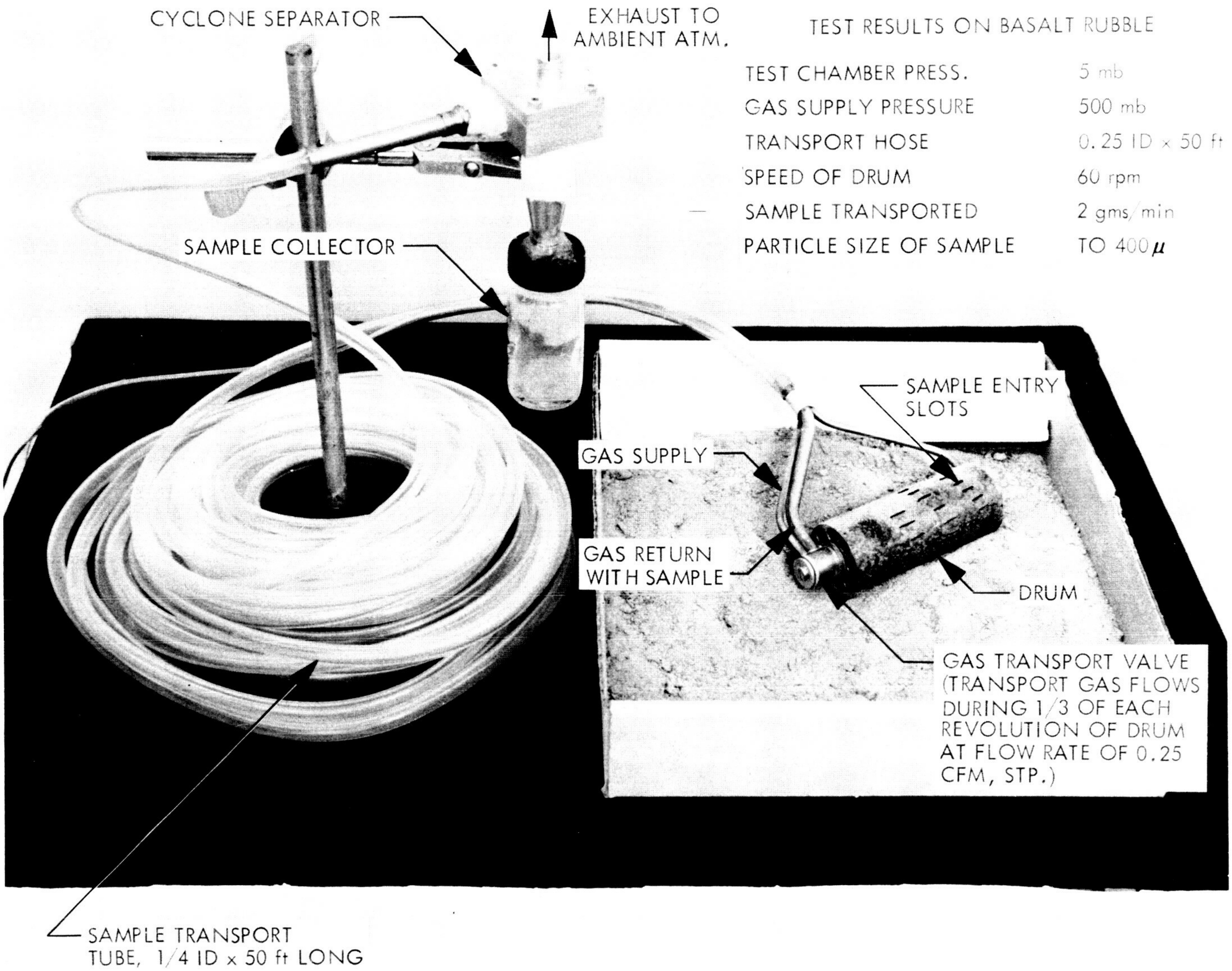

Fig. 6. Abrading drum sampler with batch aerosol transport

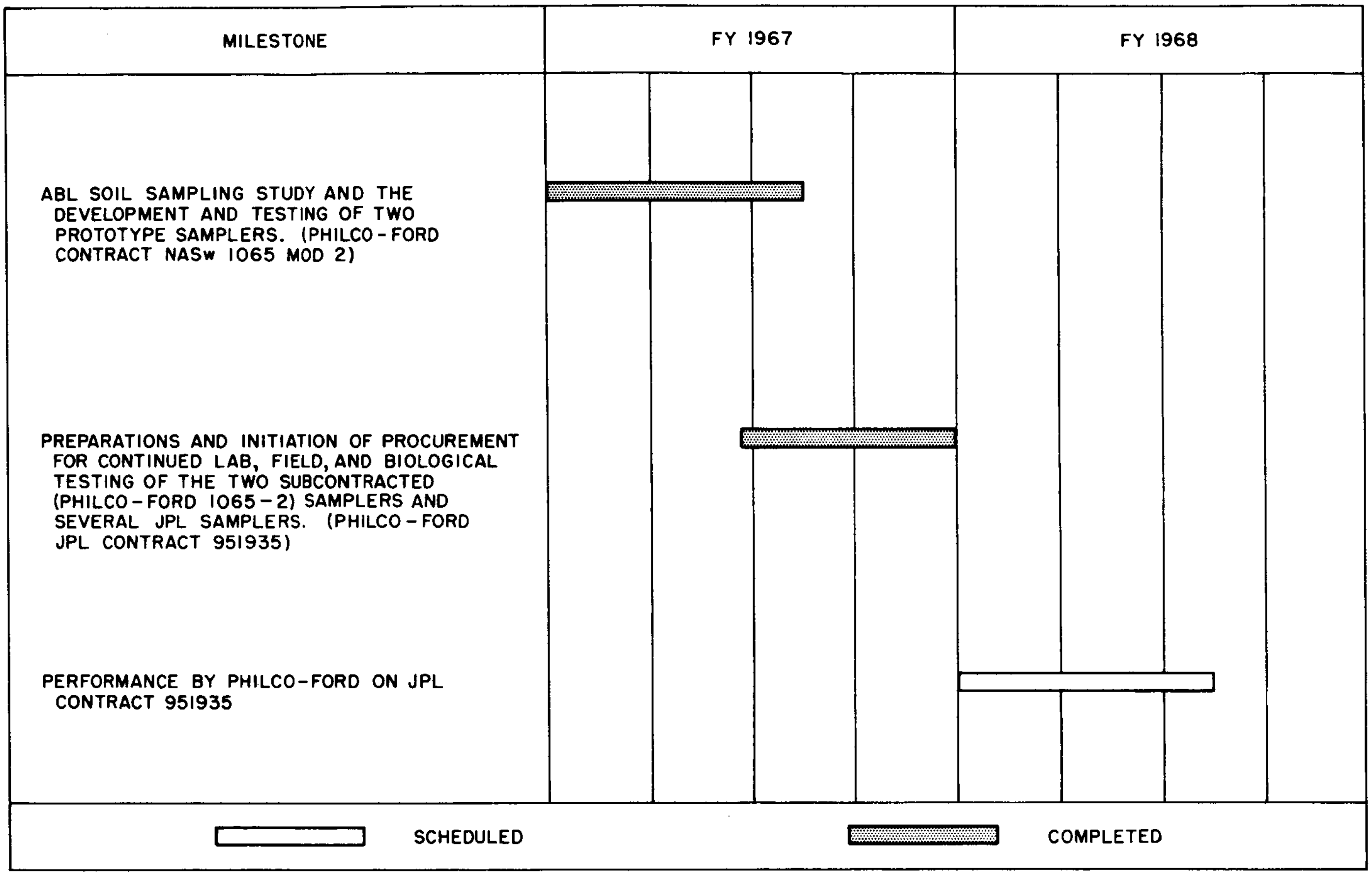

Fig. 7. Milestone chart for ABL instruments